# NAVAL POSTGRADUATE SCHOOL

**MONTEREY, CALIFORNIA**

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**MBA PROFESSIONAL REPORT**

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# NON-TACTICAL VEHICLE REPLACEMENT FOR THE DEPARTMENT OF THE NAVY'S MEDIUM- AND HEAVY-DUTY VEHICLE FLEET

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**December 2016**

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The purpose of this project is to evaluate the Navy's medium- and heavy-duty non-tactical vehicles, and determine if a business case could be made for replacing them with alternative fuel vehicles. This project analyzed Marine Corps Installation Command's Southwest Region telematics data from its non-tactical vehicles to provide the operational characteristics necessary for any proposed alternative.

Through market analysis, this project identified three primary alternative fuel vehicle technologies that potentially could be used to replace the existing medium- and heavy-duty non-tactical vehicle fleet. These technologies were electric, hybrid-electric, and compressed natural gas. All relevant costs were gathered to conduct a net present value analysis to determine whether a proposed alternative provided savings.

While many of these technologies offered the benefit of greenhouse gas reduction for the Department of the Navy, all three technologies resulted in increased costs for the medium- and heavy-duty vehicle fleet. The primary reasons that these technologies failed to provide savings was high purchase costs and a persistent depression in world oil prices. However, this project illustrates a methodology that transportation officials can use to make future decisions based on changing variable inputs. It also provides insight into market trends in the alternative fuel market.


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Submitted in partial fulfillment of the requirements for the degree of

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# NON-TACTICAL VEHICLE REPLACEMENT FOR THE DEPARTMENT OF THE NAVY'S MEDIUM- AND HEAVY-DUTY VEHICLE FLEET

## ABSTRACT


The purpose of this project is to evaluate the Navy's medium- and heavy-duty non-tactical vehicles, and determine if a business case could be made for replacing them with alternative fuel vehicles. This project analyzed Marine Corps Installation Command's Southwest Region telematics data from its non-tactical vehicles to provide the operational characteristics necessary for any proposed alternative.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| 5B | Marine Corps Logistics Base, Barstow |
| 5L | Marine Corps Base, Camp Pendleton |
| 5M | Marine Corps Air Station, Miramar |
| 5P | Marine Corps Air Ground Combat Center, Twentynine Palms |
| 5Q | Marine Corps Recruit Depot, San Diego |
| 5T | Marine Corps Mountain Warfare Training Center, Bridgeport |
| 5Y | Marine Corps Air Station, Yuma |
| AFV | Alternative fuel vehicle |
| B20 | Low concentrate biodiesel |
| B99/B100 | High concentrate biodiesel |
| BSVE | Base Support Vehicles and Equipment |
| CNG | Compressed natural gas |
| CO2 | Carbon dioxide |
| DOD | Department of Defense |
| DON | Department of the Navy |
| EV | Electric vehicle |
| EVSE | Electric vehicle supply equipment |
| FY | Fiscal year |
| GGE | Gasoline gallon equivalent |
| GPS | Global positioning system |
| GSA | General Services Administration |
| GVWR | Gross vehicle weight ratio |
| HEV | Hybrid electric vehicle |
| HDV | Heavy-duty vehicle |
| ICE | Internal combustion engine |
| IHC | International Harvester Company |
| IT | Information technology |
| kWh | kilowatt-hour |
| LDV | Light-duty vehicle |
| LPG | Liquid petroleum gas |

| | |
|---|---|
| M/O | Maintenance and operating |
| MCIWEST | Marine Corps Installation Command West |
| MCRD | Marine Corps Recruiting District |
| MDV | Medium-duty vehicle |
| MILCON | Military Construction |
| MPG | Miles per gallon |
| MPGe | Miles per gallon equivalent |
| NAVFAC | Naval Facilities Engineering Command |
| NPV | Net present value |
| NREL | National Renewable Energy Laboratory |
| NTV | Non-tactical vehicle |
| OMB | Office of Management and Budget |
| SECNAV | Secretary of the Navy |
| SW | Southwest |
| SWRFT | Southwest region fleet transportation |
| USMC | United States Marine Corps |
| VICE 2 | Vehicle Infrastructure and Cash-Flow Evaluation |
| VMT | Average Vehicle Miles Traveled |
| WTW | Well-to-wheel |

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We would like to give a special thanks to our advisors and MCIWEST for the data, expertise, and support that was provided throughout the course of this project. This project could not have been done if not for the continued access to information and local knowledge of Mr. James Vincent at Marine Corps Installation Command Southwest.

We would also like to thank the interns Ryland Mortlock, Lucas Roberts, and Holly Whittaker for their professionalism and dedication in gathering and consolidating vital data for this project.

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# I. INTRODUCTION

> The sooner we get started with alternative energy sources and recognize that fossil fuels makes us less secure as a nation, and more dangerous as a planet, the better off we'll be.
>
> —U.S. Senator Lindsey Graham,
> speaking on energy independence

## A. THE PROBLEM

To promote a more robust energy portfolio, decrease the Department of the Navy's (DON) dependence on fossil fuel, and meet Executive Order and Secretary of the Navy (SECNAV) goals, the Navy has instituted an aggressive strategy of procuring alternative fuel vehicles (AFV) and incorporating them into their non-tactical vehicle (NTV) fleet (Office of the Secretary of the Navy, n.d.c). While the debate about the future availability of fossil fuels and its impact on U.S. national security has been ongoing for decades, dramatic increases in fuel prices in the early 21st century and a change in executive leadership provided the necessary impetus for industry and government officials to begin seriously looking at alternative energy technology as a long-term, cost-effective solution to these problems. It looked as if that, finally, alternative fuel technology was mature enough and the costs were low enough to warrant a shift in the way the DON manages and acquires NTVs.

## B. THE NAVY

The Navy has significantly increased its portfolio of AFVs within its NTV fleets, specifically concerning light duty vehicles (LDV). Figure 1 represents NTVs from the United States Marine Corps (USMC) Southwest Region and shows the significant traction the DON has made in introducing alternative fuel technology into the LDVs in their fleet. For reference, Figure 2 illustrates vehicle classifications according to gross vehicle weight ratio (GVWR) with medium-duty vehicles encompassing Classes two through five and heavy-duty encompassing Classes six through eight (Idaho National Laboratory, 2015).

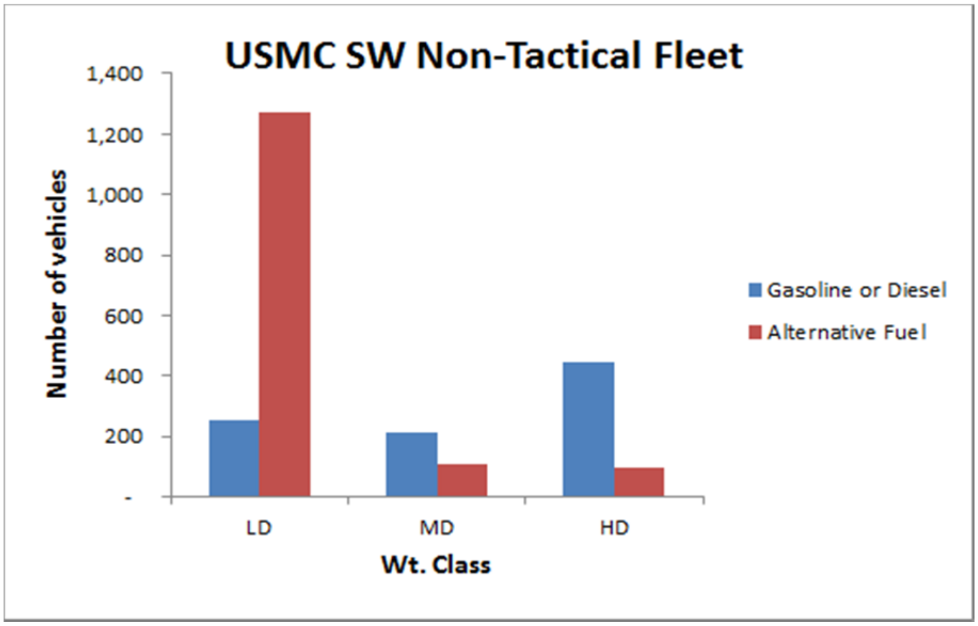



Figure 1. USMC SW NTV Fleet 2016. Source: Mortlock, Whittaker & Roberts (2016).

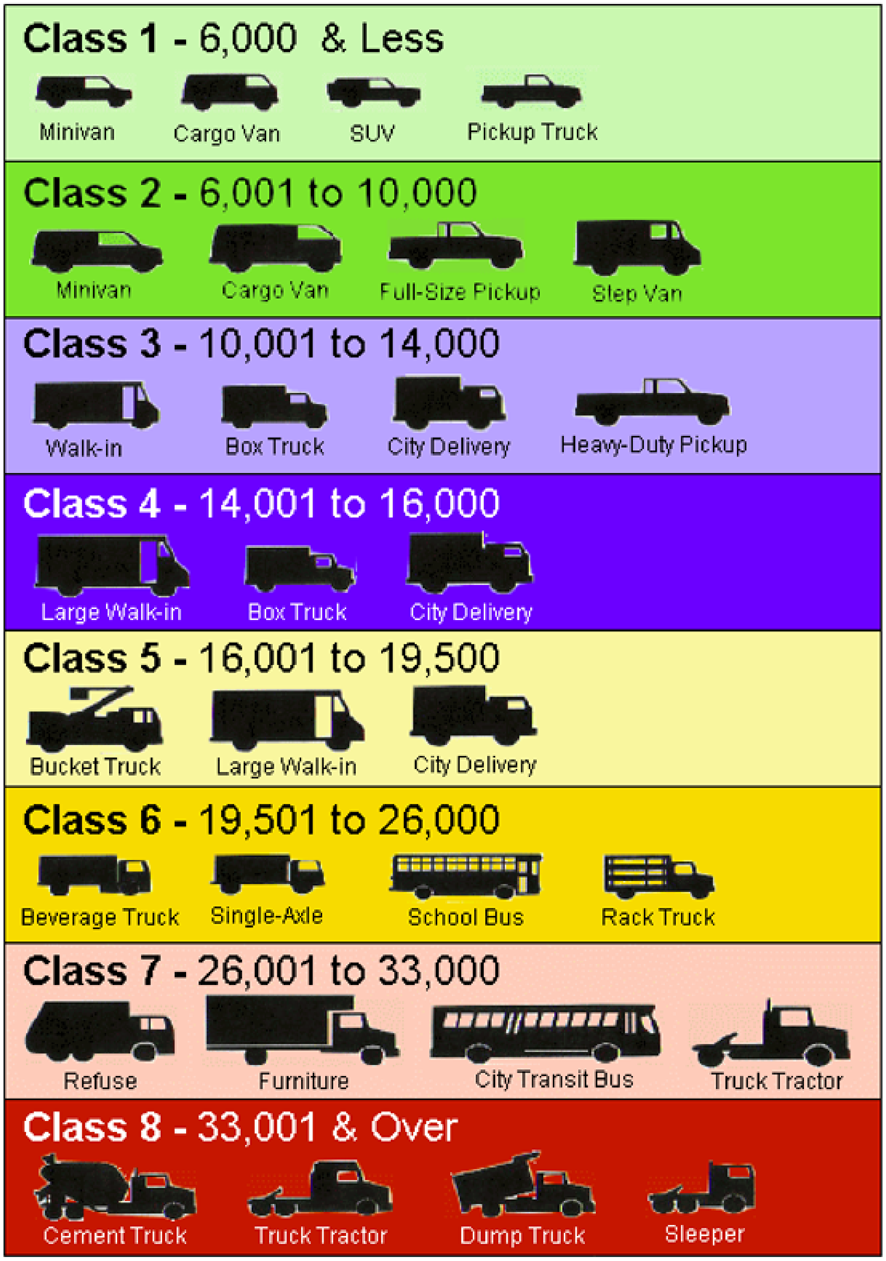



Figure 2. Vehicle Classification by Class. Source: Idaho National Laboratory (2015).

The purpose of this project is to evaluate the operational characteristics of the fleet and develop a methodology that the DON can use to replace their medium and heavy-duty NTVs with AFVs. As Figure 1 illustrates, the DON has had marked success in acquiring light duty vehicles that utilize alternative fuel technologies. However, when applying this to medium and heavy-duty vehicles the progress has been much slower primarily due to lack of available alternatives on the open market. LDV procurement accounts for a far greater portion of the vehicle manufacturing market in the United States and car manufacturers have used these economies of scale, coupled with various federal and state incentives, to penetrate the light duty vehicle market with success.

Figure 3 shows vehicle mileage, fuel consumption, and fuel economy for all vehicle weight types over a period of six and a half decades. While medium-duty vehicles (MDV) and heavy-duty vehicles (HDV) contribute to overall higher levels of fuel consumption and vehicle miles driven in comparison to LDVs, the alternative market for them has not, as of yet, matured like the light duty vehicle market. This is explained in part by the significantly higher purchase price and longer vehicle lives associated with MDVs and HDVs. Since the useful life of these vehicles can be as high as twenty years, the high purchase price makes procuring a MDV or HDV before the completion of its useful life less financially attractive due to the loss on invested capital. Additionally, technologies that have excelled in meeting the operational requirements of LDVs, like the battery electric and hybrid electric engines, are not well suited to applications in vehicles with large vehicle weights, primarily due to the weight requirement on these types of vehicles and the associated battery size needed, rendering the usefulness of these technologies obsolete.

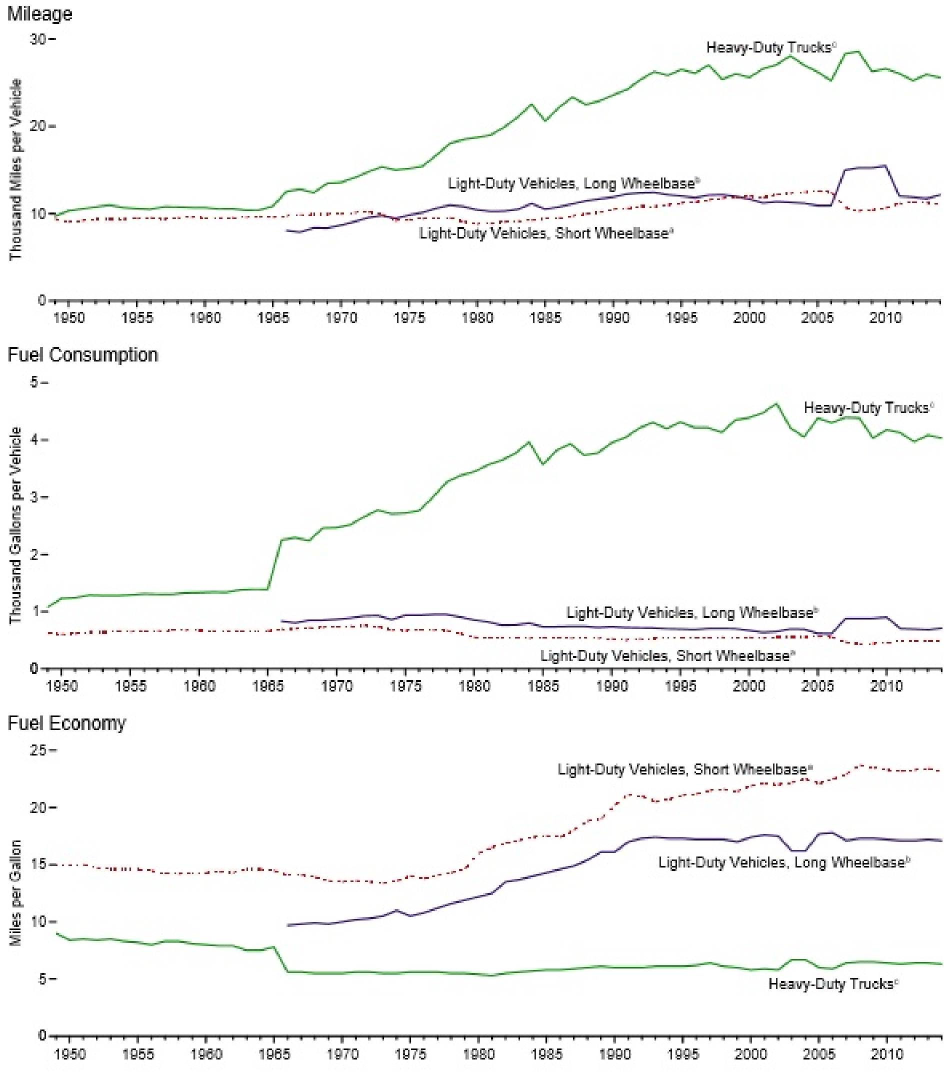



Figure 3. Motor Vehicle Mileage, Fuel Consumption, and Fuel Economy, 1949–2014. Source: U.S. Energy Information Administration (2016d).

However, since MDVs and HDVs dominate the amount of petroleum-based fuel the DON consumes, it becomes imperative to investigate and apply a methodology by which these vehicles can be replaced.

## C. MARINE CORPS INSTALLATION, WEST (MCIWEST) SOUTHWEST (SW) REGION

This project will use MCIWEST SW region as a representative sample for the greater DON NTV fleet. It will begin by analyzing the usage data for the MDVs and

HDVs in the region to determine the operational requirement and capabilities that any proposed alternative would have to meet to be deemed a viable replacement option. Using this analysis, the project will present viable alternatives and conduct a net present value (NPV) analysis, taking into consideration the purchase price, fuel costs, maintenance costs, and any associated infrastructure costs over the life of the proposed alternative and the current inventoried vehicle. The order of analysis is to identify alternatives; estimate costs of alternatives; compute the NPV of these costs; and make choices from the alternatives based upon their NPV. Using this methodology, this paper presents both viable alternatives and a methodology that other regions and installations can use for analysis at their installations. MCIWEST SW region lends itself particularly well for use for a variety of reasons.

### 1. The Region

MCIWEST SW region consists of seven bases listed as follows:

- Marine Corps Base, Camp Pendleton (5L)
- Marine Corps Recruit Depot, San Diego (5Q)
- Marine Corps Air Ground Combat Center, Twentynine Palms (5P)
- Marine Corps Air Station, Miramar (5M)
- Marine Corps Air Station, Yuma (5Y)
- Marine Corps Mountain Warfare Training Center, Bridgeport (5T)
- Marine Corps Logistics Base, Barstow (5B)

These bases represent a mix of urban and rural terrain. Additionally, they represent a range of topographical conditions from relatively flat to mountainous, as well as varying climatological conditions ranging from arid and desert to snowy and wet. By picking this region, this project is able to identify viable alternatives for various operating environments that can be applicable to almost any other DON region worldwide.

### 2. Telematics

MCIWEST SW region has taken an aggressive approach in implementing the use of telematics devices to capture various metrics of usage associated with their NTV fleet. Because they have done so, this project is able to analyze both how they currently utilize the MDV and HDV vehicles they have, along with the operational requirements the fleet managers list as required for a particular type of vehicle. Detailed telematics allows the project team to understand the operational needs of viable alternatives. Additionally, telematics data allows the project team to weigh those alternatives against various additional desired operational capabilities available when conducting a side-by-side comparison.

Another value of the use of telematics information is the detailed fuel consumption that is provided by the reports. Since MCIWEST SW region has detailed telematics information, it is easy to calculate the current fuel consumption of a MDV or HDV, as well as use the mileage drive to estimate the fuel or equivalent energy consumption of a proposed alternative.

### 3. The Fleet

The MCIWEST SW Region includes the telematics and consumption data for over 2,400 NTVs. Table 1 illustrates the regions various vehicle types, as well as fuel types currently in use. As a relatively large region, the number of NTVs operated and maintained provides a sufficiently large quantity of vehicles, making it applicable for use in statistical analysis and as a representative sample for other DON regions.

Table 1. MCIWEST SW Region NTV Fleet. Source: Mortlock, Whittaker, & Roberts (2016).

| Fuel Type | LD | MD | HD |
|---|---|---|---|
| Gasoline | 189 | 16 | 17 |
| Diesel | 64 | 195 | 432 |
| Gasoline Hybrid | 40 | - | - |
| Diesel Hybrid | - | 9 | 4 |
| CNG | 48 | 6 | 18 |
| E-85 FF | 1,144 | 81 | - |
| Electric | 42 | 2 | 45 |
| Hydrogen | - | - | - |
| LPG | - | 11 | 31 |
| Unknown | 73 | 3 | 12 |
| **Grand Total** | **1,600** | **323** | **559** |

| Fuel Type | LD | MD | HD |
|---|---|---|---|
| Gasoline or Diesel | 253 | 211 | 449 |
| Alternative Fuel | 1,274 | 109 | 98 |
| **Grand Total*:** | **1,527** | **320** | **547** |
| Non Alternative Fuel | 16.6% | 65.9% | 82.1% |
| Alternative Fuel | 83.4% | 34.1% | 17.9% |

* not counting unknown fuel type

# II. BACKGROUND

> As I hope you've heard, I've made energy security and energy independence a top priority for the Navy and Marine Corps…Energy security is national security. Too much of our oil comes from either potentially or actually volatile places on earth. We would never allow some of these countries that we buy energy from to build our aircraft or our ships or our ground vehicles. But through a dependence on oil, we give them a say on whether those aircraft fly, where those ships sail, or those ground vehicles operate. Seeking alternative fuels and seeking to use fuel more efficiently makes us better warfighters. It's that simple. That's our principle mission, and that's the main reason we're doing this. It's also going to save some lives.
>
> —Ray Mabus,
> U.S. Secretary of the Navy, 2011–present

## A. PERSPECTIVE

Energy security and energy independence are vital to our national security. The Navy's and Marine Corps' ability to reduce their dependency on fossil fuels and create an energy portfolio rich with alternative fuel sources will have a significant impact on whether or not the DON can meet its mission and objectives in the 21st century.

Broadly speaking, the federal government discusses energy under three major umbrellas: foreign dependence on energy, fossil fuel's contribution to global warming and climate change, and the United States energy sector and how it relates to economic well-being and growth. While the DOD contributes on all these fronts, the primary catalyst for seeking alternative energy sources, their associated technologies, and for becoming more efficient with energy use is because of foreign dependence.

In 2010, the United States consumed approximately 294 billion gallons of petroleum and other petroleum liquids (U.S. Energy Information Administration, n.d.b). Figure 4 shows that while the federal government makes up only approximately two percent of that number, the DOD makes up 93 percent of federal government consumption. Additionally, the DOD represents the single largest consumer of petroleum in the world.

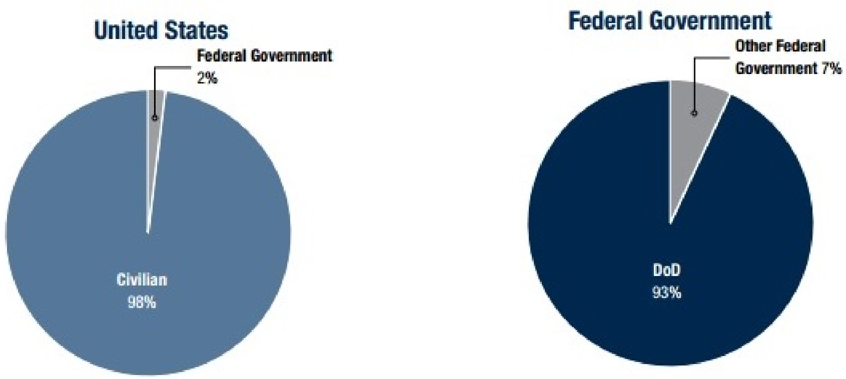



Figure 4. Petroleum Consumption—National and DOD Perspective.
Source: Department of the Navy (2010).

While energy consumption represents more than just fossil fuels, and fossil fuels comprise more than just petroleum and petroleum products, the Navy's NTV fleet consists of primarily petroleum based vehicles that utilize the internal combustion engine. The Navy categorizes the energy consumption for NTVs under shore energy, which makes up six percent of all DON fuel consumption, as shown in Figure 5.

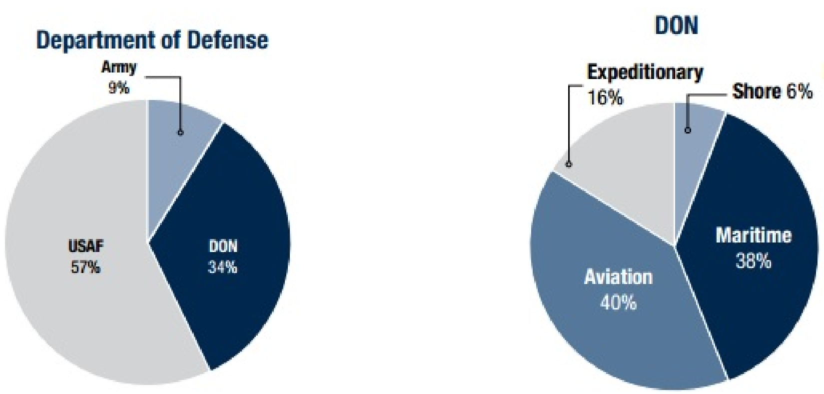



Figure 5. Petroleum Consumption—DOD and DON Perspective.
Source: Department of the Navy (2010).

## B. POLICY

Policy can be broken up into statute, executive order, and DOD & DON Instruction. Below, he relevant policy documents to this study are examined below.

### 1. Statute and Executive Order

The Energy Independence and Security Act of 2007, signed by President George W. Bush, sought to move the United States toward energy independence and security. Specifically, Title 1 of the act saw the first efficiency standard applied to medium and heavy-duty vehicles. The act was written to promote alternative fuel vehicle technology by increasing the corporate average fuel economy standards and promoting research for plug-in hybrid electrics through battery loan programs, grants, and hybrid vehicle tax incentives. The act also included a mandate stating that, relative to a 2005 baseline, federal fleets must reduce petroleum consumption by twenty percent and increase alternative fuel consumption by ten percent by 2015 (Energy Independence and Security Act of 2007).

Executive Order 13423, also signed by President George W. Bush, required federal agencies to comply with these laws and conduct energy and environmentally related activities to support the goal of strengthening the management of energy, transportation, and the environment. It specifically mandated that any agency that operated a fleet of at least twenty vehicles must reduce total petroleum consumption by 2 percent a year from the 2005 baseline through 2015. It also stipulated that fleets must increase alternative fuel consumption by ten percent each year and that the use of plug-in hybrids must be used if they are available and cost competitive with conventional vehicles (Executive Order No. 13,423, 2007).

Furthering on this, President Barack H. Obama signed Executive Order 13514, in October 2009, which expanded the two percent petroleum reduction annually through 2020 or 30 percent of the 2005 baseline. However, in March 2015, President Obama issued Executive Order 13693 titled *Planning for Federal Sustainability in the Next Decade*. This order revoked Executive Order 13423 and 13514. The purpose of this order was to maintain federal leadership in greenhouse gas emission reduction and sustainability standards, and in doing so, require federal agencies that operate fleets of at least 20 motor vehicles to achieve reduction in fleet-wide per mile, greenhouse gas emissions of four percent by the end of FY 2017 from a 2014 baseline. This executive order further stated that these agencies should meet a 15 percent reduction by FY 2021 and not less than 30 percent by FY 2025 (Executive Order No. 13,693, 2015).

Executive order number 13693 marked a shift in executive dialogue by changing the metric standards from petroleum-reduction-based to greenhouse-gas-emission reduction based. This provided an impetus for the DON to do more than simply reduce petroleum consumption and increase alternative fuel consumption, but to increase it specifically using those technologies that reduced greenhouse gas (GHG) emissions to meet these goals.

### 2. SECNAV Goals

The previous policy framework described applies more broadly to the federal government writ large. However, in 2009 the Secretary of the Navy, Ray Mabus, issued five major goals aimed at gaining energy independence for the DON (Office of the Secretary of the Navy, n.d.a). These goals are

- Increase alternative energy use DON-wide by mandating that 50 percent of the DON's total energy consumption will come from alternative sources by 2020.
- Increase alternative energy ashore by specifying that at least 50 percent of shore-based energy requirements will be produced from alternative sources by 2020. Additionally, 50 percent of Navy and Marine Corps installations will be net-zero.
- Demonstrate a Green Strike Group in local operations by 2012 and sail the "Great Green Fleet" by 2016.
- Reduce non-tactical petroleum use by the DON's commercial fleet by 50 percent by 2015.
- Create energy efficient evaluation factors that must be used in evaluating and awarding all DON contracts (Office of the Secretary of the Navy, n.d.a).

The Secretary of the Navy's goals provide a more aggressive standard across the board to be applied to the DON. These goals applied to the Navy and Marine Corps shore energy portfolio that provided the foundation for this study.

### 3. Non-Tactical Vehicles

Naval Facilities Engineering Command (NAVFAC) is designated as the central manager of the Navy's base support vehicles and equipment (BSVE) program. As such, they are primarily responsible for meeting the SECNAV goals placed on the Navy's NTV fleet. The NTV fleet consists of approximately 52,352 light, medium, and heavy-duty vehicles (GSA, 2016). Figure 6 shows the relative mix between petroleum-based and non-petroleum-based alternative vehicles as of 2016. While the DON is making significant progress toward meeting its goals, there is still a need to incorporate AFVs into NAVFAC's NTV fleet, specifically when it comes to medium and heavy-duty vehicles.

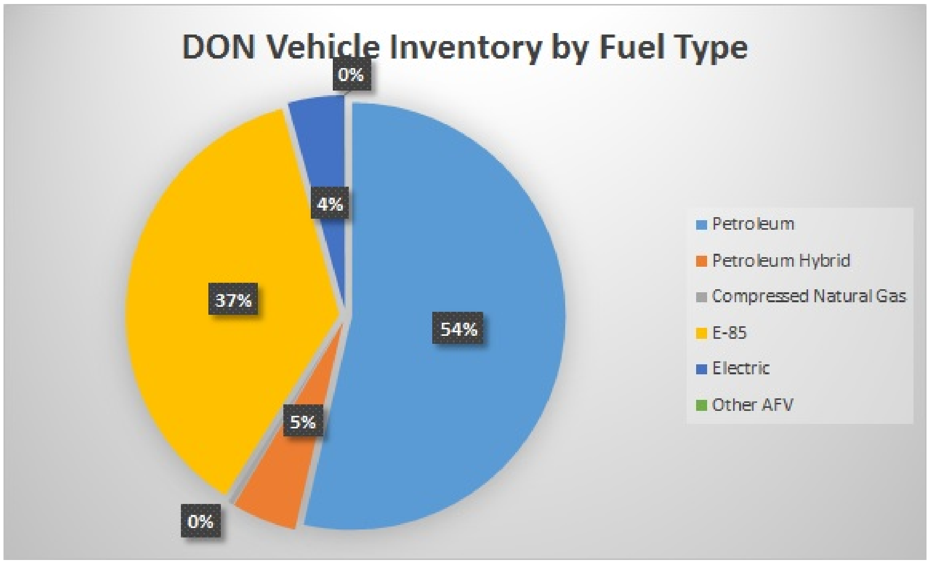



Figure 6. DON Vehicle Inventory by Fuel Type. Adapted from GSA (2016).

NAVFAC has made significant gains in their LDV acquisition, with almost half of their LDVs now consisting of AFVs (Office of the Secretary of the Navy, n.d.b). However, a large barrier to entry for implementing AFVs into the DON's NTV fleet lies in the associated infrastructure costs and service life for medium and heavy-duty vehicles. To be cost effective, NAVFAC fleet managers must make long-term infrastructure investments and replace petroleum based medium and heavy-duty vehicles to use that infrastructure. This is often more difficult than replacing one vehicle at the end of their service life, and requires multi-year planning with MILCON funding, which comes with required congressional approval and evaluation.

# III. MCIWEST SW REGION NTV FLEET

To understand the region's NTV data, this chapter breaks down the use of telematics devices, how the different sets of data available are classified and consolidated, and the analytical methods employed.

## A. TELEMATICS

Section 3 of Executive Order 13693 signed in March 2015, directs federal agencies to take appropriate actions to meet the new goals set forth, beginning in FY 2016. In particular, it mandates that if an agency operates a fleet of at least 20 motor vehicles, it should improve its vehicle efficiency management through the deployment of vehicle telematics for all new light-, medium-, and heavy-duty vehicles no later than two years after the date of the order. This mandate provides the necessary policy for NAVFAC and MCICOM to generate requirements to fund the implementation of telematics devices in their NTV fleets.

Telematics devices are electronic data collection devices that use either GPS tracking or connect to a vehicle's computer. They give owners and fleet managers data on how a vehicle is used, how efficiently it is used, and where the vehicle travels. MCIWEST SW Region has aggressively implemented the use of such telematics devices, which provides a valuable resource for analyzing the actual operating characteristics of the vehicles in their fleet. The data from these devices helps managers better identify and address inefficiencies while striving to meet fuel consumption and GHG reduction requirements. By using vehicle telematics devices with an associated information technology (IT) system, fleet managers can more accurately select viable AFV alternatives for current vehicles in their fleet by understanding the actual operational requirements demanded of those items. The purpose of this project is not to question the need or justification for a particular vehicle, but rather ensure that whatever alternative is proposed can meet the operational demands currently placed on the vehicles in question. Given that the MCIWEST SW Region has leaned forward in implementing these devices, they represent an appropriate sample to use in illustrating the methodology of replacing medium and heavy-duty vehicles with AFVs through the analysis of telematics data.

There are many additional benefits of using telematics devices other than providing a more accurate fuel-efficiency metric for fleet managers. Future use and analysis of the data provided by these devices can provide managers information as to the operational characteristics of a particular platform, and inform decisions about potential optimization applications given utilization data.

## B. DATA CONSOLIDATION

In conducting an analysis of the MCIWEST SW Region, the project pulled twelve months of telematics data. By using one year of data, the assumption was made that the operational demands on the vehicles would account for any seasonal and operational variations the vehicles experience over annual cycles. Therefore, telematics data from June 2015 to May 2016 was used as the basis for these analyses. Since the focus of this project was MDV and HDV replacement, LDVs were removed from the data set to begin the analysis.

### 1. Data Sources

There were three primary sources of data, Network Fleet telematics devices, DriveCam telematics devices, and paper mileage reports in conducting our analysis. MCIWEST SW Region’s fleet consisted of both vehicles owned by the region and vehicles leased through GSA.

To begin our analysis we consolidated all vehicles and their associated data into a master spreadsheet. As described in detail below, different vehicles in the region had different types of data. Some of the vehicles had DriveCam, Network Fleet, and paper mileage reports, some vehicles had only two of the three types of reports, and other vehicles had only mileage reports. Given this, we were able to verify the data against the different sources where applicable to help give more validity to the data that was collected.

#### *a. DriveCam*

DriveCam telematics devices are installed on General Services Administration (GSA) leased vehicles. They were the first telematics devices implemented by the region and were provided as part of the lease of the vehicle. DriveCam provided data via a global positioning system (GPS) device. Using this device, we were able to run two reports for use in this project. The first was a DriveCam fuel data report. This report provided 46,000 data points from 439 different medium and heavy-duty vehicles. Using these data points, we were able to derive the total distance traveled in miles, the number of days through the year utilized, and the miles per day utilized for different vehicles.

The second report was the DriveCam daily summary report. This report provided 50,000 data points, which provided distance in miles, number of trips, and miles per trip over the course of the year for different vehicles.

However, DriveCam did have its limitations. While provided to the region at a low cost since it was included in the lease, the telematics devices did not have the proper harness employed with them to hook up directly to the vehicle's computer system. The result was that the device sent coordinate positions when the vehicle was in use, but could not provide fuel efficiency data and other vehicle data that could be provided from a device that could integrate into the vehicle's computer system. MCIWEST SW Region is moving away from the use of these types of telematics devices upon the expiration of the vehicle's leases and going toward devices that can directly plug into the vehicle computer.

#### *b. Network Fleet*

Network Fleet was the next generation of telematics devices used by the region. While the region has plans to expand the use of these devices, they are currently only installed on 337 vehicles in their fleet. Network Fleet data provided two valuable reports for use in this project. The first was the Network Fleet fuel summary report. This report provided the distance in miles, the fuel used in gallons, and the fuel efficiency via miles per gallon (MPG) for different vehicles. Since these devices were plugged into the vehicle's computer, they provided more detailed information concerning fuel usage and efficiency. A total of 3,600 data points for the 337 vehicles were provided over the course of the year using these reports.

The second report provided by Network Fleet data is the stop detail reports. These reports provided the distance in miles, trip duration, vehicle stop duration, and miles per day utilized of the different vehicles. The stop detail reports provided a daily overview of the 337 vehicles and recorded each time a vehicle was turned on, how long it was used, and how long it was turned off on any given day. These reports provided over 900,000 data points for use in statistical analysis.

#### *c. Mileage Reports*

Mileage reports are paper reports filled out by vehicle operators upon completion of using the vehicles. This information is collected and compiled monthly by the region for each vehicle. By using the previous month's monthly odometer reading, we were able to derive the total miles traveled over the course of the year for 961 different vehicles.

#### *d. Other Sources*

In addition to the telematics data and mileage reports listed above, we asked the region to provide us with any additional information they have regarding the NTV fleet. Our primary goal was to account for every medium and heavy-duty vehicle that the region had in inventory in order to conduct a proper analysis as to the viability of replacing them with AFVs to achieve the DON's goals.

The additional information provided included a fleet equipment inventory spreadsheet and a telematics installation spreadsheet provided by the MCIWEST SW Region. Figure 7 visually illustrates how the different data sources described above were consolidated into a master spreadsheet for future statistical analysis.

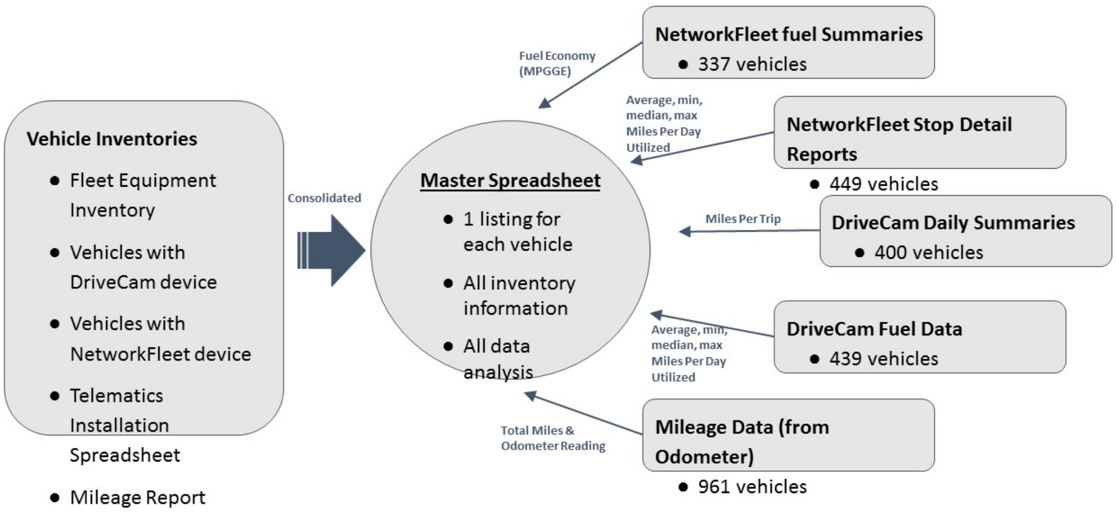



Figure 7. MCIWEST SW Region Data Consolidation Visualization. Adapted from Mortlock, Whittaker, & Roberts (2016).

### 2. Categorization

Upon completion of creating a master spreadsheet, we needed a way to further organize the vehicles into like types. The LDVs were already removed from the analysis, as our study was not focused on that category of vehicle. We decided the most appropriate way to categorize the vehicles for analysis was by applying an operational category to the different vehicles in the spreadsheet. The primary justification for this was the assumption that if we could group vehicles that had similar operational characteristics and find alternatives that satisfied those operational requirements, then the proposed alternatives would work for any vehicle within that categorization group.

After a thorough review of the database, the vehicles were categorized into eleven different classifications. These classifications aligned with the vehicle descriptions provided by the region for use in their mater inventory spreadsheets. The categories and example images for reference are as follows:

### *a. 11 Types*

The vehicle classification types can be broken into heavy- and medium-duty vehicles.

(i) Heavy-duty Vehicles

The classification of is demonstrated in Figures 8 through 12.

Figure 8. Passenger Bus. Source: Blue Bird (n.d.).

Figure 9. Tractor Trailer. Source: Freightliner (n.d.).


Figure 10. Sweeper. Source: Tymco (n.d.).


Figure 11. Fire Truck – Class A Pumper. Source: Pierce (n.d.)

Figure 12. Heavy-duty Maintenance Truck. Source: Commercial truck trader (n.d.a)

(ii) Other Heavy-Duty Vehicle

Other heavy-duty vehicles encompassed items classified as heavy duty, but lacking in significant quantities to warrant a unique classification. They included vehicles such as asphalting equipment, cranes, agricultural equipment, snow removal equipment, and construction equipment.

(iii) Medium-Duty

The classification of medium-duty vehicles is demonstrated in Figures 13 through 16.


Figure 13. Ambulance. Source: Ford (n.d.)

Figure 14. Stake Truck. Source: Commercial Truck Trader (n.d.b)

Figure 15. Step Van. Source: Auto Park Fleet (n.d.).

Figure 16. Cargo Van. Source: Chevrolet (n.d.).

(iv) Other Medium-Duty Trucks

Other medium-duty trucks included items such as miscellaneous maintenance trucks, airfield support equipment, refuse vehicles, and smaller recovery vehicles. These items lacked the number of vehicles and telematics data to make them appealing for analysis or consideration when searching for AFV alternatives.

### *b. Focus on Transportation Types*

After reviewing the vehicles in their groupings, there were a number of vehicle types that fell into the category of having little to no data, were utilized infrequently, or were considered warehouse equipment. These vehicles were removed from consideration for the study because they represented vehicle types that would have a small market penetration in comparison to transportation type vehicles, and, in many cases, were used so infrequently that a capital investment would be difficult to justify for replacing them.

Some of the vehicle types removed from consideration were as follows:

- Snow mobiles and other snow equipment
- Forklifts and other warehouse niche equipment
- Bulldozers, cranes, excavators, and other weight handling equipment
- Mobile command posts

After removing these vehicles from consideration, we reviewed the remaining transportation vehicle types, and assessed the quantity and quality of telematics data that we had for each vehicle type. Of significant importance for consideration was whether the telematics data provided a significant number of data points in regard to fuel economy and number of days and miles utilized.

The result was five vehicle types for which adequate telematics data existed. Our analysis and search for alternatives focused on these five vehicle-classification types.

### *c. Heavy-Duty Vehicles*

(i) Bus

Table 2 provides a summary of the data that was available for buses.

Table 2. Bus Vehicle Data—70 Total Vehicles. Source: Mortlock, Whittaker, & Roberts (2016).

| | Vehicles Listed | What It Tells Us |
|---|---|---|
| **Network Fleet Fuel Data** | 21 | MPG |
| **DriveCam Daily Summaries** | 54 | Miles/Trip |
| **NetworkFleet Stop Detail** | 22 | Miles/Day * |
| **Mileage Report** | 32 | Yearly Miles |
| **DriveCam Fuel Data** | 54 | Miles/Day * |

The * denotes average miles/day utilized. Additional statistical information such as median, maximum, minimum miles/day were utilized for analysis but not shown here.

(ii) Fire Truck

Table 3 provides a summary of the data that was available for fire trucks.

Table 3. Fire Truck Vehicle Data—106 Total Vehicles. Source: Mortlock, Whittaker, & Roberts (2016).

| | Vehicles Listed | What It Tells Us |
|---|---|---|
| **Network Fleet Fuel Data** | 0 | MPG |
| **DriveCam Daily Summaries** | 31 | Miles/Trip |
| **NetworkFleet Stop Detail** | 0 | Miles/Day * |
| **Mileage Report** | 38 | Yearly Miles |
| **DriveCam Fuel Data** | 32 | Miles/Day * |

The * denotes average miles/day utilized. Additional statistical information such as median, maximum, minimum miles/day were utilized for analysis but not shown here. Not all Fire Trucks had data available, but a large enough sample of them did. Therefore, the operational characteristics for alternatives were applied from the data that was available.

(iii)Tractor-Trailer

Table 4 provides a summary of the data that was available for tractor-trailers.

Table 4. Tractor Trailer Vehicle Data—62 Total Vehicles. Source: Mortlock, Whittaker, & Roberts (2016).

| | Vehicles Listed | What It Tells Us |
|---|---|---|
| **Network Fleet Fuel Data** | 0 | MPG |
| **DriveCam Daily Summaries** | 36 | Miles/Trip |
| **NetworkFleet Stop Detail** | 0 | Miles/Day * |
| **Mileage Report** | 31 | Yearly Miles |
| **DriveCam Fuel Data** | 37 | Miles/Day * |

The * denotes average miles/day utilized. Additional statistical information such as median, maximum, minimum miles/day were utilized for analysis but not shown here.

### *d. Medium-Duty Vehicles*

(i) Van

Table 5 provides a summary of the data that was available for vans.

Table 5. Van Vehicle Data—49 Total Vehicles. Source: Mortlock, Whittaker, & Roberts (2016).

| | Vehicles Listed | What it tells us |
|---|---|---|
| **Network Fleet Fuel Data** | 1 | MPG |
| **DriveCam Daily Summaries** | 17 | Miles Per Trip |
| **NetworkFleet Stop Detail** | 1 | Miles Per Day* |
| **Mileage Report** | 27 | Yearly Miles |
| **DriveCam Fuel Data** | 18 | Miles Per Day* |

The * denotes average miles/day utilized. Additional statistical information such as median, maximum, minimum miles/day were utilized for analysis but not shown here.

(ii) Step Van

Table 6 provides a summary of the data that was available for step vans.

Table 6. Step Van Vehicle Data—57 Total Vehicles. Source: Mortlock, Whittaker, & Roberts (2016).

| | **Vehicles Listed** | **What It Tells Us** |
|---|---|---|
| **Network Fleet Fuel Data** | 27 | MPG |
| **DriveCam Daily Summaries** | 4 | Miles/Trip |
| **NetworkFleet Stop Detail** | 29 | Miles/Day * |
| **Mileage Report** | 34 | Yearly Miles |
| **DriveCam Fuel Data** | 4 | Miles/Day * |

The * denotes average miles/day utilized. Additional statistical information such as median, maximum, minimum miles/day were utilized for analysis but not shown here.

## C. STATISTICAL ANALYSIS

For the five vehicles types just described, an analysis of vehicle usage and performance through statistical analysis of the telematics data was performed to derive the operational characteristics that would define the characteristics necessary for any AFV alternative to be proposed for replacement. The metrics used and how they were derived are described in the following paragraphs.

### 1. Average MPG

For vehicles that had Network Fleet telematics data, monthly fuel data reports for the twelve months of study were pulled. For each vehicle, the mean MPG was derived by using Equation 1.

$$Average\ MPG = \frac{\sum Monthly\ MPG\ Data}{12\ months} \tag{1}$$

### 2. Average Miles / Trip

For vehicles that had DriveCam telematics data, a trip is defined as an engine shut-off. Therefore, to calculate the average miles per trip, the sum of the miles per trip was divided by the number of trips as shown in Equation 2.

$$\text{Miles Per Trip} = \frac{\sum \text{Miles Per Trip}}{\text{Total Number of Trips}} \tag{2}$$

### 3. Average Miles / Day Utilized

For vehicles that had Network Fleet telematics data, the Network Fleet stop detail reports provided the total number of miles per day. If a vehicle only had DriveCam telematics devices, the DriveCam fuel data reports provided the miles per day for analysis. Since Network Fleet stop detail data provided more detailed information, if a vehicle had both devices, the Network Fleet stop detail was used after cross-referencing the two data sources. To derive the average miles/day utilized, the sum of the miles per day over the year were divided by the total number of days in the one-year period, as shown in Equation 3.

$$\text{Average Miles/Day Utilized} = \frac{\sum \text{Miles/Day}}{\text{Total Number of Days}} \tag{3}$$

### 4. Minimum Miles / Day Utilized

To derive minimum miles per day utilized, we analyzed the lowest mileage reading for each vehicle in the sample. As it turned out, none of the vehicles analyzed were utilized every day. Therefore, the minimum miles per day utilized turned out to be zero. This metric proved it was not as useful as the other statistical measures used, but did provide a valuable low-end baseline to compare against the maximum and average miles per day utilized.

### 5. Median Miles / Day Utilized

To ensure that the average miles per day utilized did not represent a value that was inconsistent due to an unusually large data point, the median miles per day utilized was computed to provide insight as to whether the median or average miles per day utilized was more representative. To derive the median miles per day utilized, the sum of the median miles per day for each month was divided by the total number of months, as shown in Equation 4.

$$\text{Median miles/day utilized} = \frac{\sum_{n=1}^{12}(\text{Max. Miles Utilized - Min. Miles Utilized})}{12} \qquad (4)$$

### 6. Maximum Miles/Day Utilized

Similar to minimum miles per day utilized was derived, the maximum miles per day utilized was determined by taking the highest mileage reading for each vehicle type over the period. It provided a high end when comparing it to minimum, median, and average miles per day utilized to ensure that any AFV alternative recommended for a vehicle type could meet the maximum mileage required of it.

### 7. Average Annual Miles

To calculate the average annual miles for each vehicle in our sample, data from outside the twelve months identified was used. However, this data came from annual mileage data on the mileage reports provided and not from telematics data. To derive the average annual miles, the sum of annual mileage was divided by the total number of years for which information was available on a particular vehicle. Equation 5 shows the method of calculation.

$$\text{Avg. Annual Miles} = \frac{\sum_{n=1}^{i}(\textit{Annual}\ \text{Mileage})}{i} \qquad (5)$$

## D. ANALYTICAL RESULTS

For each of the five vehicle types under consideration for replacement, the statistical analysis referenced in the previous section was performed. The results of the analysis are provided in Table 7.

Table 7. Statistical Analysis by Vehicle Classification Type. Source: Mortlock, Whittaker, & Roberts (2016).

| Vehicle Classification | Quantity | Average MPG | Average Miles per trip | Average Miles per Day Utilized | Minimum Miles per Day Utilized | Median Miles per Day Utilized | Maximum Miles per Day Utilized | Average Yearly Miles |
|---|---|---|---|---|---|---|---|---|
| BUSES | 70 | 6.60 (21) | 31.25 (53) | 98.54 (57) | <1 mile (57) | 73.80 (57) | 1,330.2 (57) | 16,311 (34) |
| FIRE TRUCKS | 106 | NO DATA | 8.02 (33) | 22.42 (34) | <1 mile (34) | 15.82 (34) | 753.56 (34) | 4067 (38) |
| TRACTOR TRAILERS | 62 | NO DATA | 30.01 (36) | 136.36 (37) | <1 mile (37) | 96.12 (37) | 877.817 (37) | 20,601 (31) |
| STEP VANS | 57 | 9.33 (27) | 7.07 (3) | 31.13 (30) | <1 mile (30) | 30.35 (30) | 309.5 (30) | 7533 (34) |
| VANS | 52 | 8.03 (1) | 18.53 (17) | 72.59 (19) | <1 mile (19) | 55.77 (19) | 467.992 (19) | 7884 (19) |

Numbers in parenthesis indicate the quantity of vehicles for which data was available for analysis.

Of note, the average MPG for each vehicle type is low. This is not necessarily surprising given what was presented Figure 3. However, it is important to point out that, given the fact that the majority of these vehicles are still fossil fuel based, any AFV alternatives would provide both increased fuel efficiency with the secondary benefit of reducing GHG emissions as well.

The results of the utilization of each vehicle type provide the operational boundaries that any AFV alternative must meet to be considered a viable replacement option. Additionally, it provides insight as to the level of infrastructure necessary that AFV alternatives would need at a particular base, given the usage of each vehicle type.

### 1. Buses

The next logical step in conducting the analysis was to break down the information we had on each vehicle type under consideration. Table 8 provides a summary of the 70 buses in MCIWEST SW Region's NTV fleet. As shown in the table, data was available for buses at every location in the region except for Barstow. Fuel economy data via telematics is only available with the use of Network Fleet fuel data reports, and therefore, was not available at three base locations.

Table 8. Statistical Analysis for Buses by Base. Source: Mortlock, Whittaker, & Roberts (2016).

| Base | Quant. | Average MPG | Average Miles per trip | Average Miles per Day Utilized | Minimum Miles per Day Utilized | Median Miles per Day Utilized | Maximum Miles per Day Utilized | Average Yearly Miles |
|---|---|---|---|---|---|---|---|---|
| 5L | 36 | 6.60 (15) | 28.01 (33) | 90.88 (34) | <1 mile (34) | 72.33 (34) | 682.806 (34) | 17330 (32) |
| 5M | 6 | NO DATA | 25.94 (6) | 106.15 (6) | <1 mile (6) | 71.86 (6) | 1330.2 (6) | NO DATA |
| 5P | 12 | 6.65 (5) | 26.25 (2) | 136.15 (5) | <1 mile (5) | 129.95 (5) | 586.9 (5) | NO DATA |
| 5Q | 6 | NO DATA | 10.27 (3) | 38.46 (3) | <1 mile (3) | 28.461 (3) | 170.268 (3) | NO DATA |
| 5T | 3 | 6.46 (1) | 63.83 (3) | 119.67 (3) | <1 mile (3) | 91.139 (3) | 531.9 (3) | NO DATA |
| 5Y | 7 | NO DATA | 50.28 (6) | 122.48 (6) | <1 mile (6) | 51.331 (6) | 524.431 (6) | NO DATA |

Numbers in parenthesis indicate the quantity of vehicles for which data was available for analysis.

The data provides the framework for fleet managers at the region in defining the operational requirements a bus must meet at a particular location to be a viable alternative. Additionally, the data was analyzed to determine the current fuel type of buses in the region. As shown in Table 9, the majority of buses are fueled by diesel, but the region has begun implementing buses fueled with compressed natural gas (CNG). Of note, the data shows that the current CNG buses achieve greater fuel efficiency, though the region utilizes them on trips of shorter distances.

Table 9. Analysis of Buses by Fuel Type. Source: Mortlock, Whittaker, & Roberts (2016).

| Fuel Type | Quant. | Average MPG | Average Miles per trip | Average Miles per Day Utilized | Minimum Miles per Day Utilized | Median Miles per Day Utilized | Maximum Miles per Day Utilized | Average Yearly Miles |
|---|---|---|---|---|---|---|---|---|
| CNG | 11 | 7.30 (3) | 17.82 (11) | 72.77 (11) | <1 mile (11) | 63.96 (11) | 551.6 (11) | 15193 (4) |
| Diesel | 54 | 6.49 (18) | 34.77 (42) | 103.08 (45) | <1 mile (45) | 76.99 (45) | 1330.2 (45) | 17636 (28) |
| Unknown | 5 | NO DATA | 14.42 (1) | 49.40 (1) | <1 mile (1) | 38.94 (1) | 217.6 (1) | NO DATA |

Numbers in parenthesis indicate the quantity of vehicles for which data was available for analysis.

Data for buses was also analyzed by current manufacturer to determine if a particular model was outperforming another, as well as to determine the base case characteristics in future net present value (NPV) analysis. As shown in Table 10, the majority of buses in the region are from two manufacturers and seem to achieve relatively similar results in terms of fuel economy. Though Thomas Built buses appear to achieve slightly greater MPG, on average, those particular vehicles drive farther than their Blue Bird counterparts and is assumed to account for the slightly increased fuel economy.

Table 10. Analysis of Buses by Manufacturer. Source: Mortlock, Whittaker, & Roberts (2016).

| MAKE | Quant. | Average MPG | Average Miles per trip | Average Miles per Day Utilized | Minimum Miles per Day Utilized | Median Miles per Day Utilized | Maximum Miles per Day Utilized | Average Yearly Miles |
|---|---|---|---|---|---|---|---|---|
| Blue Bird | 49 | 6.52 (18) | 27.19 (40) | 93.21 (43) | <1 mile (43) | 71.99 (43) | 1330.2 (43) | 17354 (27) |
| Motor Coach Industries | 1 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| Thomas Built Buses | 19 | 7.09 (3) | 46.21 (12) | 119.7 (13) | <1 mile (13) | 82.48 (13) | 524.431 (13) | 12289 (7) |
| Unknown | 1 | NO DATA | 14.42 (1) | 49.40 (1) | <1 mile (1) | 38.935 (1) | 217.579 (1) | NO DATA |

Numbers in parentheses indicate the quantity of vehicles for which data was available for analysis.

#### *a. Data Visualization*

Vehicles for which Network Fleet telematics devices were used provided an opportunity using the Network Fleet stop detail reports. For purposes of operational analysis, the grid coordinates of the start and stop locations for various trips could be plotted on a map overlay to provide fleet managers with a visualization of the data. This visualization provided the project team with a better understanding of how the vehicles were utilized.

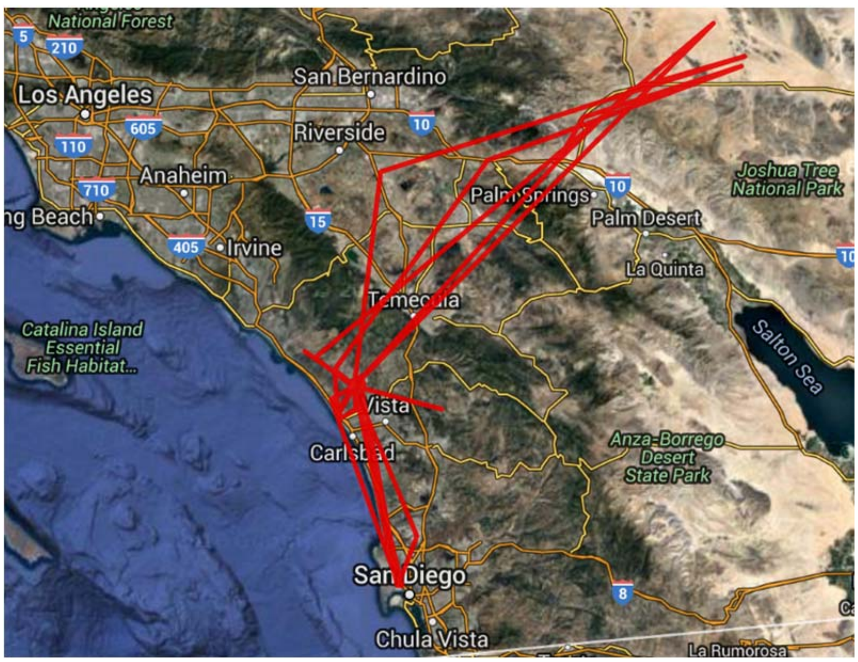
The thin red lines in the data visualization represent a trip, with all the lines representing the trips accumulated for the sample year for a particular vehicle. While the lines do not follow the actual path the vehicle took, they do show the start and stopping locations that a particular vehicle makes throughout the course of the year. Using this information, in conjunction with the statistical analysis, further informs the fleet manager of the usage patterns and operational characteristics of a particular vehicle.

Twenty-two buses had the data necessary to create data visualization maps. Sixteen of these buses were located at Camp Pendleton, five were located at Twentynine Palms, and one was located at Bridgeport. An analysis of buses from each base follows.

(i) Camp Pendleton

Buses at Camp Pendleton consisted of primarily diesel fuel types, but a small number of CNG types as well. For visualization purposes, three buses were used. Two buses were diesel and represented both a bus that had higher than average trip lengths and lower than average trip lengths. The third vehicle was a CNG bus.

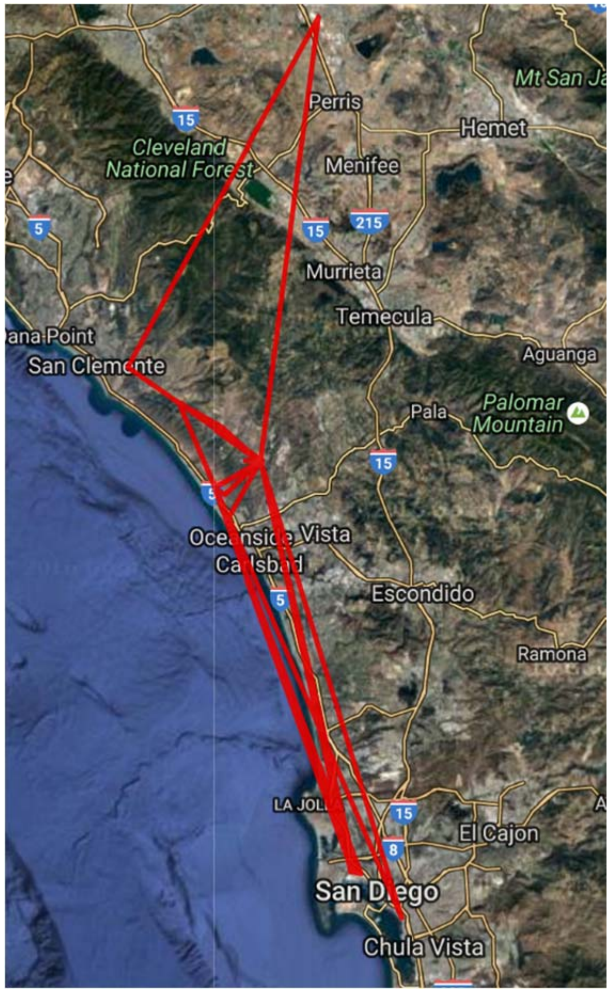
Figure 17 is a visualization of a diesel bus at Camp Pendleton with higher than average trip lengths. The data shows that the majority of trips the bus takes is to Twentynine Palms or MCRD San Diego.




Fuel Type: Diesel Average Miles per Day Utilized: 113

Figure 17. Bus G320405H Data Visualization. Source: Mortlock, Whittaker, & Roberts (2016).

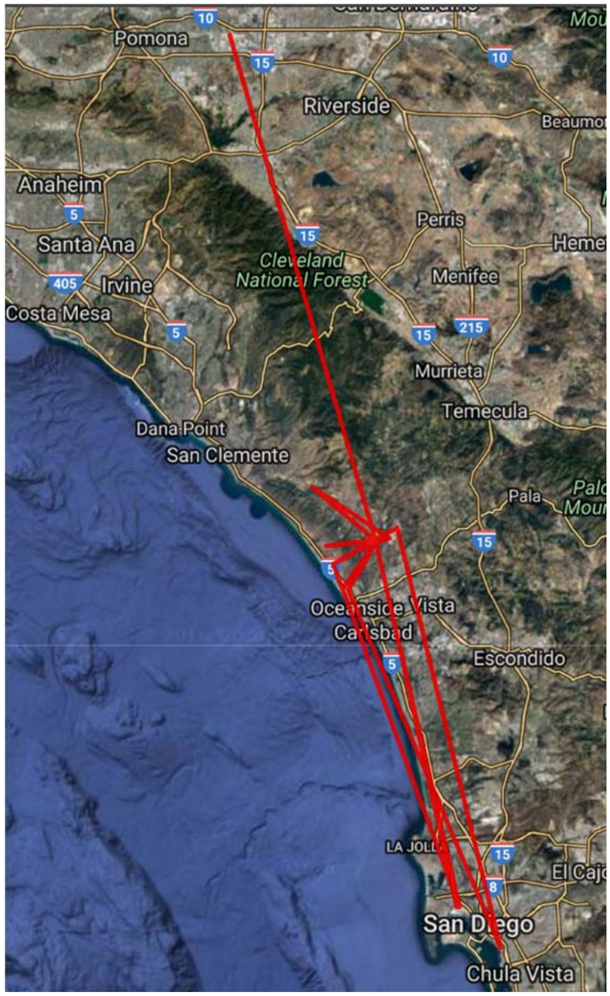
Figure 18 represents a diesel bus at Camp Pendleton with lower than average trip lengths. As shown, this bus appears to be traveling between Pendleton North and Pendleton South with occasional trips to MCRD San Diego and other destinations.




Fuel Type: Diesel Average Miles per Day Utilized: 68

Figure 18. Bus G320413H Data Visualization. Source: Mortlock, Whittaker, & Roberts (2016).

Figure 19 represents the CNG bus sample from Camp Pendleton. The data indicates that this particular bus traveled similar to the diesel bus shown in Figure 18, and was used for trips of shorter than average length.



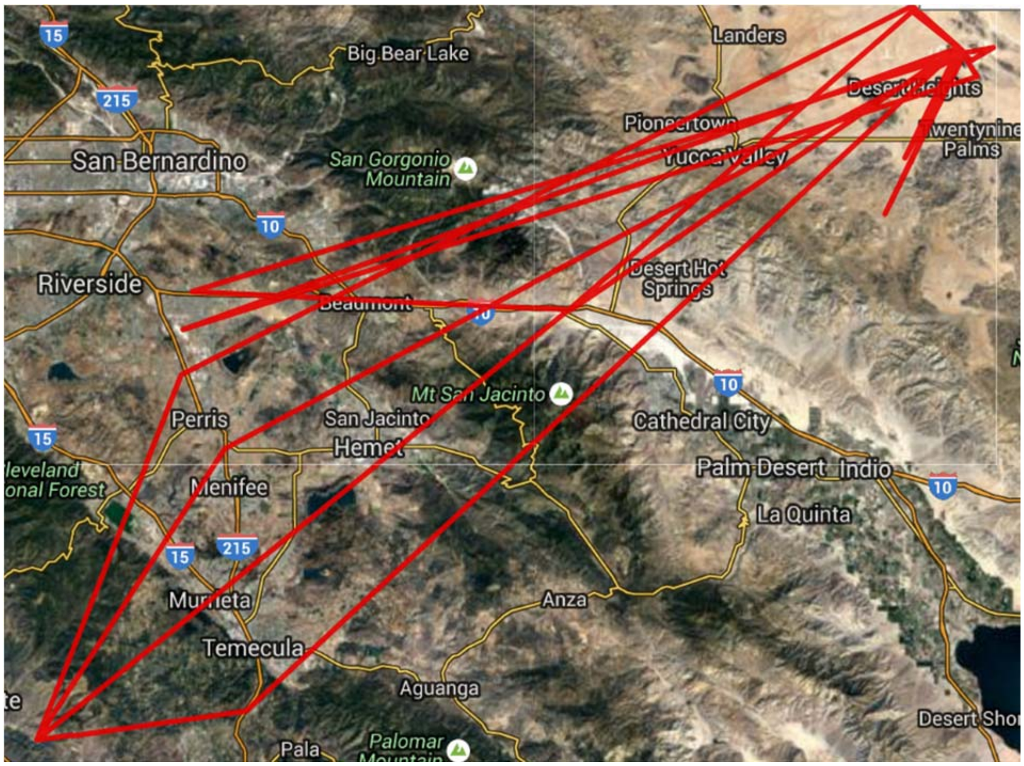

Fuel Type: CNG Average Miles per Day Utilized: 84

Figure 19. Bus G320313K Data Visualization. Source: Mortlock, Whittaker, & Roberts (2016).

(ii) Twentynine Palms

Buses at Twentynine Palms also consisted of diesel and CNG fuel types, three and two of each respectively. Since the number of vehicles with data appropriate for data visualization was small, one of each fuel type was chosen for visualization.

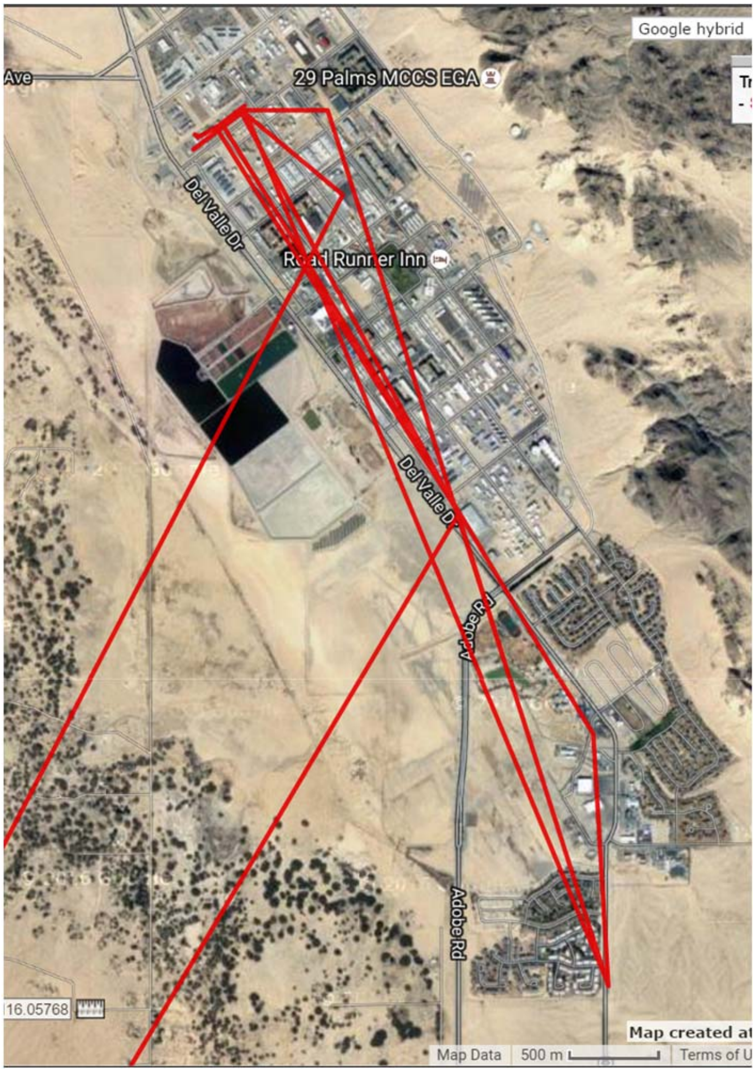
Analysis of the five buses show a consistency in the miles per day utilized. Diesel buses at this location average 160 miles per day utilized, while CNG buses at this location average 90 miles per day utilized. This indicates that region managers use the CNG buses for trips of shorter duration on average, probably due to the fact that CNG infrastructure is limited to certain locations. Figure 20 represents a diesel bus from Twentynine Palms. The visualization shows that almost all the trips occur primarily to and from Camp Pendleton.




Fuel Type: Diesel Average Miles per Day Utilized: 161

Figure 20. Bus G320378H Data Visualization. Source: Mortlock, Whittaker, & Roberts (2016).

Figure 21 represents a CNG bus at Twentynine Palms. It is interesting to note, with the exception of a few trips south, CNG buses at this location primarily traveling back and forth across base. Lack of available CNG infrastructure, in route, is considered the primary cause of this behavior.

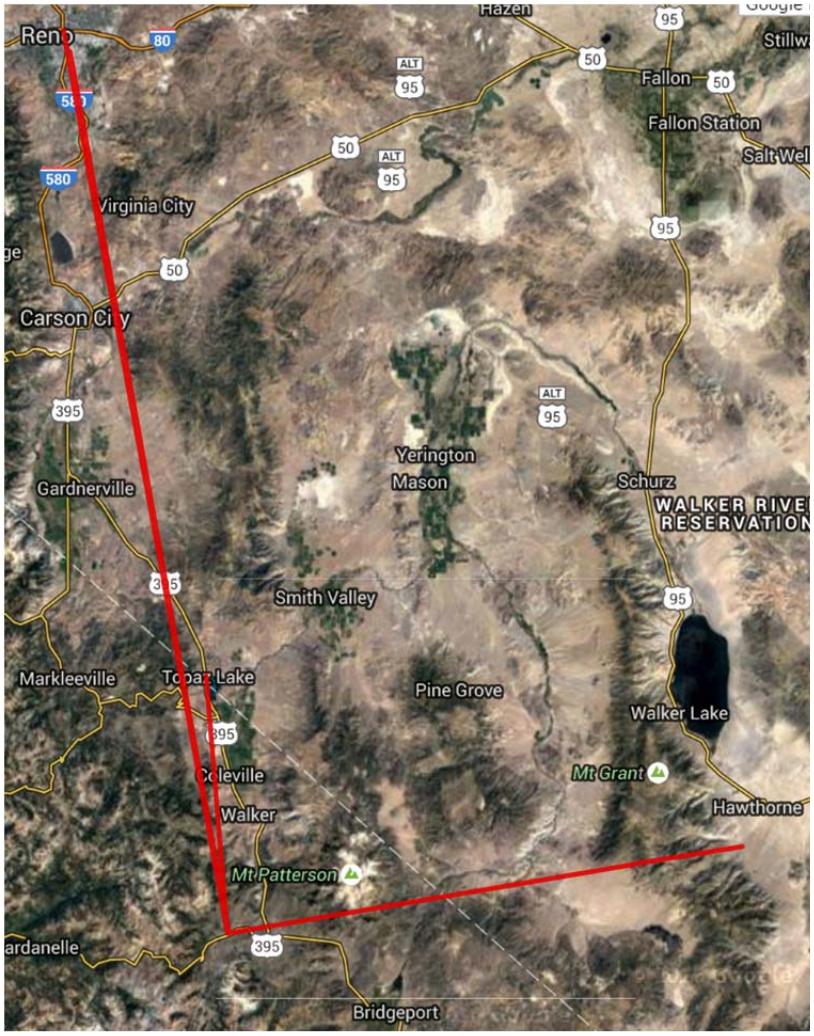



Fuel Type: CNG  Average Miles per Day Utilized: 90

Figure 21. Bus G320378H Data Visualization. Source: Mortlock, Whittaker, & Roberts (2016).

(iii)Bridgeport

Only one bus at Bridgeport had the necessary telematics data to do a data visualization map. Figure 22 shows this particular CNG bus. The lines indicate that trips from this base, for this vehicle, are primarily along three routes: north to Reno, north to Topaz Lake, and east toward Hawthorne.




Fuel Type: CNG Average Miles per Day Utilized: 80

Figure 22. Bus G320414H Data Visualization. Source: Mortlock, Whittaker, & Roberts (2016).

The data visualization for buses across the three bases from which appropriate telematics data was available, coupled with the statistical analysis of all buses within the sample, provide the fleet managers and project team with the necessary information with regard to the current fleet of buses. This information will be used to define operationally what AFV alternatives must meet as well as the tradeoffs between the current fleet and any proposed alternatives.

### 2. Fire Trucks

The data collected on all 106 fire trucks come from one base, Camp Pendleton. Additionally, all fire trucks were diesel fueled. Therefore, the data was analyzed by manufacturer. Table 11 shows the breakdown of the 106 fire trucks in the region.

Table 11. Analysis of Fire Trucks by Manufacturer. Source: Mortlock, Whittaker, & Roberts (2016).

| MAKE | Quant. | Average MPG | Average Miles per trip | Average Miles per Day | Minimum Miles per Day Utilized | Median Miles per Day Utilized | Maximum Miles per Day Utilized | Average Yearly Miles |
|---|---|---|---|---|---|---|---|---|
| DAM | 1 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| EMO | 1 | NO DATA | 5.29 (1) | 11.56 (1) | <1 mile (1) | 4.611 (1) | 135.676(1) | NO DATA |
| FMD | 14 | NO DATA | 7.43 (5) | 28.37 (5) | <1 mile (5) | 17.62 (5) | 753.57 (5) | 4970 (7) |
| GMC | 1 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| IHC | 13 | NO DATA | 10.57 (8) | 18.98 (8) | <1 mile (8) | 11.16 (8) | 374.4 (8) | 1721 (9) |
| OSH | 25 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | 619 (7) |
| PIC | 37 | NO DATA | 6.72 (17) | 21.68 (17) | <1 mile (17) | 17.53 (17) | 94.66 (17) | 7041 (14) |
| PRD | 1 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| WSM | 3 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| UNKNOWN | 3 | NO DATA | 11.64 (2) | 29.54 (3) | <1 mile (3) | 19.31 (3) | 682.427 (3) | NO DATA |
| D-8000 | 1 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| DASH-D8000 | 2 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| 2674-6X6 | 1 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| E-8121 | 1 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| CFR NUR UNIT | 1 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| ARROW | 1 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |

Numbers in parenthesis indicate the quantity of vehicles for which data was available for analysis.

The analysis of fire trucks is unique because of the limited amount of time they are utilized. Not surprisingly, as emergency vehicles, they have a very low utilization rate. Also, of note from the data, is that these vehicles tend to be older than the other vehicles under consideration, with some fire truck models being of a 1984 variety. In considering AFV alternatives for fire trucks, it is important that any proposed change take into consideration not only the telematics data, but also the physical characteristics of the current replacement.

As none of the fire trucks had Network Fleet telematics devices, data visualization was not available. However, as discussed, these vehicles are utilized infrequently, and tend to stay on Camp Pendleton to be able to respond in emergency situations as required. While fire trucks provided the quantity of vehicles and quantity of data points desirable for consideration, their high costs, uniquely long service lives, and limited availability for alternatives in the marketplace make it difficult to find economically viable replacement alternatives.

### 3. Tractor-Trailer

Telematics data was available for tractor-trailers at every base except for Marine Corps Recruiting District (MCRD) San Diego. As shown in Table 12, Bridgeport appeared to utilize this vehicle type more than the other bases with Barstow showing an extremely low utilization.

Table 12. Statistical Analysis of Tractor Trailers by Base. Source: Mortlock, Whittaker, & Roberts (2016).

| Base | Quant. | Average MPG | Average Miles per trip | Average Miles per Day Utilized | Minimum Miles per Day Utilized | Median Miles per Day Utilized | Maximum Miles per Day Utilized | Average Yearly Miles |
|---|---|---|---|---|---|---|---|---|
| 5B | 4 | NO DATA | 7.42 (4) | 44.31 (4) | <1 mile (4) | 24.02 (4) | 340.151 (4) | NO DATA |
| 5L | 36 | NO DATA | 25.60 (25) | 127.30 (25) | <1 mile (25) | 76.36 (25) | 588.358 (25) | 20601 (31) |
| 5M | 7 | NO DATA | 28.19 (2) | 140.41 (2) | <1 mile (2) | 98.28 (2) | 500.12 (2) | NO DATA |
| 5P | 8 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| 5T | 2 | NO DATA | 89.09 (1) | 265.54 (2) | <1 mile (2) | 318.45 (2) | 877.817 (2) | NO DATA |
| 5Y | 5 | NO DATA | 66.32 (4) | 218.47 (4) | <1 mile (4) | 179.4 (4) | 536.47 (4) | NO DATA |

Numbers in parenthesis indicate the quantity of vehicles for which data was available for analysis.

Tractor-trailers account for the highest average yearly miles of any of the vehicle types under consideration. Additionally, all 62-tractor trailers that are included in the sample are fueled by diesel. Given this, any AFV alternative that could meet the operational requirements as given in Table 12, would help the region both reduce fossil fuel consumption and decrease GHG emissions. Table 13 breaks down the sample of tractor-trailers by manufacturer. Of note, it appears that those vehicles, in this set, manufactured by International Harvester Company (IHC) traveled significantly less on average than others did.

Table 13. Statistical Analysis of Tractor Trailers by Manufacturer. Source: Mortlock, Whittaker, & Roberts (2016).

| MAKE | Quant. | Average MPG | Average Miles per trip | Average Miles per Day Utilized | Minimum Miles per Day Utilized | Median Miles per Day Utilized | Maximum Miles per Day Utilized | Average Yearly Miles |
|---|---|---|---|---|---|---|---|---|
| FTL | 20 | NO DATA | 53.69 (5) | 175.63 (5) | <1 mile (5) | 144.01 (5) | 536.47 (5) | 20937 (8) |
| IHC | 20 | NO DATA | 16.27 (16) | 94 (16) | <1 mile (16) | 53.83 (16) | 530.297 (16) | 15170 (10) |
| MCI | 3 | NO DATA | 53.76 (2) | 131.08 (2) | <1 mile (2) | 122.8 (2) | 434.46 (2) | 39085 (1) |
| VOL | 18 | NO DATA | 34.52 (12) | 170.91 (13) | <1 mile (13) | 124.77 (13) | 877.817 (13) | 23362(12) |
| UNKNOWN | 1 | NO DATA | 29.84 (1) | 179.31 (1) | <1 mile (1) | 107.3015 (1) | 502.733 (1) | NO DATA |

Numbers in parenthesis indicate the quantity of vehicles for which data was available for analysis.

Since stop detail reports were not available on the sample of tractor-trailers, data visualization could not be conducted as an additional method of understanding the operational characteristics of this vehicle type.

#### 4. Step Vans

Data for step vans was available from across four of the seven bases. Information on step vans was not available at the Barstow, Sand Diego, or Bridgeport locations. As shown in Table 14, the data indicates that the vehicles are used for trips of short distance. Additionally, it shows that, for the vehicles where fuel economy data was available, the step vans at the region get very low average MPG.

Table 14. Statistical Analysis of Step Vans by Base. Source: Mortlock, Whittaker, & Roberts (2016).

| Base | Quant. | Average MPG | Average Miles per trip | Average Miles per Day Utilized | Minimum Miles per Day Utilized | Median Miles per Day Utilized | Maximum Miles per Day Utilized | Average Yearly Miles |
|---|---|---|---|---|---|---|---|---|
| 5L | 43 | 9.44 (25) | 7.07 (4) | 32.04 (28) | <1 mile (28) | 31.306 (28) | 309.5 (28) | 7533 (34) |
| 5M | 2 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| 5P | 9 | 7.94 (2) | NO DATA | 18.33 (2) | <1 mile (2) | 16.975 (2) | 48.6 (2) | NO DATA |
| 5Y | 2 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |

Numbers in parenthesis indicate the quantity of vehicles for which data was available for analysis.

In contrast to the other vehicle types previously examined, when analyzing step vans by fuel type, the majority of these vehicles are currently fueled by E85, or flex fuel. Flex fuel is an ethanol-gasoline blend that is considered an alternative fuel type, and, the DON has invested in placing E85 stations at Navy and Marine Corps bases. Table 15 shows the step vans for the region broken out by fuel type.

Table 15. Statistical Analysis of Step Vans by Fuel Type. Source: Mortlock, Whittaker, & Roberts (2016).

| Fuel Type | Quant. | Average MPG | Average Miles per trip | Average Miles per Day Utilized | Minimum Miles per Day Utilized | Median Miles per Day Utilized | Maximum Miles per Day Utilized | Average Yearly Miles |
|---|---|---|---|---|---|---|---|---|
| E85 FF | 53 | 9.35 (26) | 7.07 (4) | 31.44 (29) | <1 mile (29) | 30.79 (29) | 309.5 (29) | 7621 (33) |
| Gasoline | 4 | 8.87 (1) | NO DATA | 22.05 (1) | <1 mile (1) | 17.65 (1) | 97.5 (1) | 4648 (1) |

Numbers in parenthesis indicate the quantity of vehicles for which data was available for analysis.

#### *a. Data Visualization*

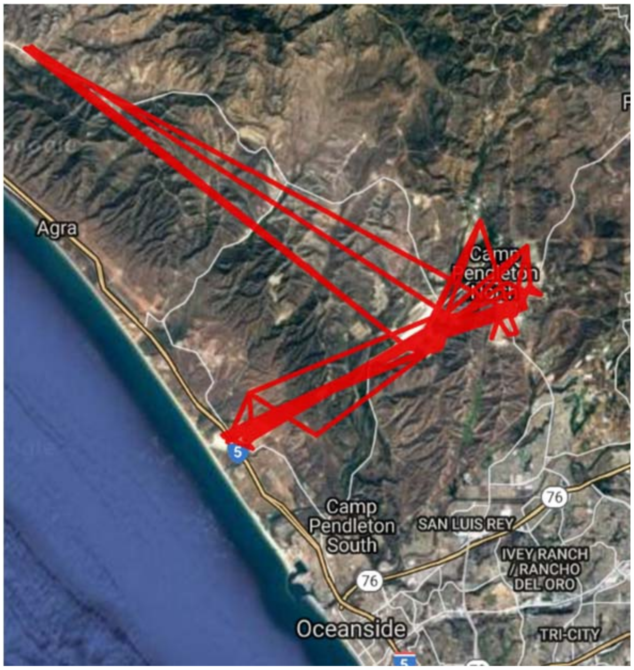
Network Fleet telematics data is available for 29 step vans. 27 are located at the Camp Pendleton and two are located at the Twentynine Palms location.

(i) Camp Pendleton

Step vans at Camp Pendleton included 26 vehicles fueled by E85 and one vehicle fueled by gasoline. For data visualization purposes, the gasoline step van is analyzed.

Additionally, three step vans are analyzed. One that has higher than average utilization, one that has average utilization, and one that has lower than average utilization.

As shown in Figures 23 through 26, step vans at Camp Pendleton tend to stay on the base. This can be misleading since Camp Pendleton is an extremely large base consisting of 125,000 acres ranging from 20–3100 feet in elevation. That said, a few of these vehicles appear to be used for very short distance trips on one particular part of the base. Given the low utilization, they could be attractive candidates for a plug in electric vehicle.

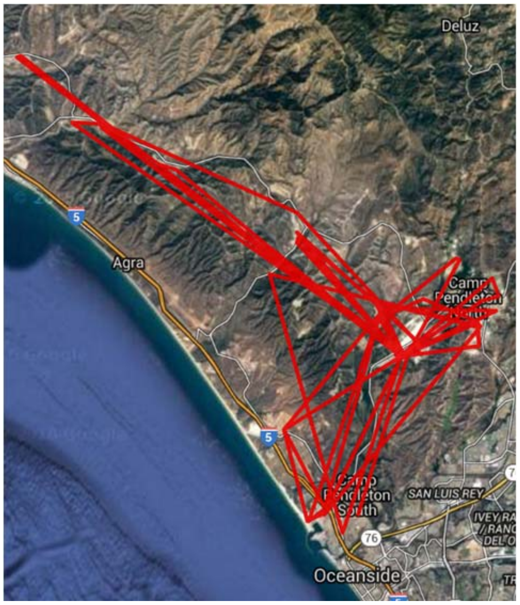



Fuel Type: Gasoline Average Miles per Day Utilized: 22

Figure 23. Step Van G33145H Data Visualization. Source: Mortlock, Whittaker, & Roberts (2016).

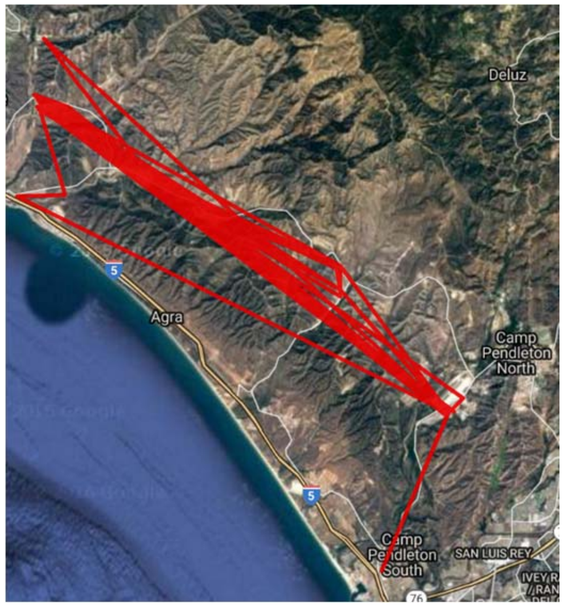

Fuel Type: E85    Average Miles per Day Utilized: 12

Figure 24. Step Van G433903K Data Visualization. Source: Mortlock, Whittaker, & Roberts (2016).




Fuel Type: E85    Average Miles per Day Utilized: 34

Figure 25. Step van G433124H Data Visualization. Source: Mortlock, Whittaker, & Roberts (2016).




Fuel Type: E85    Average Miles per Day Utilized: 63

Figure 26. Step van G433123H Data Visualization. Source: Mortlock, Whittaker, & Roberts (2016).

(ii) Twentynine Palms

The data visualization in Figure 27 represents one of the two-step vans at this location. As shown, all of its trips are confined to the base, making it an attractive candidate for AFVs that have low range.


Fuel Type: Gasoline Average Miles per Day Utilized: 63

Figure 27. Step van G433598L Data Visualization.
Source: Mortlock, Whittaker, & Roberts (2016).

### 5. Vans

Data for vans was available from five of the seven bases. The two locations for which van data was not available were at the Yuma and Barstow bases. As shown in Table 16, data for vans indicate that average and median trip length were inconsistent from base to base. It is evident, however, that average miles per day was not a good measure of the average distances traveled due to the large number of trips of extremely low mileage.

Table 16. Statistical Analysis of Vans by Base. Source: Mortlock, Whittaker, & Roberts (2016).

| Base | Quant. | Average MPG | Average Miles per trip | Average Miles per Day Utilized | Minimum Miles per Day Utilized | Median Miles per Day Utilized | Maximum Miles per Day Utilized | Average Yearly Miles |
|---|---|---|---|---|---|---|---|---|
| 5L | 32 | 8.03 (1) | 15.30 (11) | 16.14 (12) | <1 mile (12) | 53.33 (12) | 467.99 (12) | 7884 (27) |
| 5M | 6 | NO DATA | 21.42 (3) | 89.72 (3) | <1 mile (3) | 64.49 (3) | 435.973 (3) | NO DATA |
| 5P | 7 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| 5Q | 4 | NO DATA | 12.16 (1) | 35.64 (1) | <1 mile (1) | 8.022 (1) | 366.199 (1) | NO DATA |
| 5T | 3 | NO DATA | 35.09 (2) | 96.14 (3) | <1 mile (3) | 72.69 (3) | 448.319 (3) | NO DATA |

Numbers in parenthesis indicate the quantity of vehicles for which data was available for analysis.

Although median miles per trip tend to be more representative for daily utilization, there did seem to be a clearer pattern in use when looking at the data for vans by fuel type. As shown in Table 17, it appears the region is capitalizing on the operational capabilities of the diesel hybrid and taking further trips. Alternatively, the flex fuel vans seem to be taking far shorter trips, perhaps due to limitations of refueling infrastructure or simply less operational need by those users.

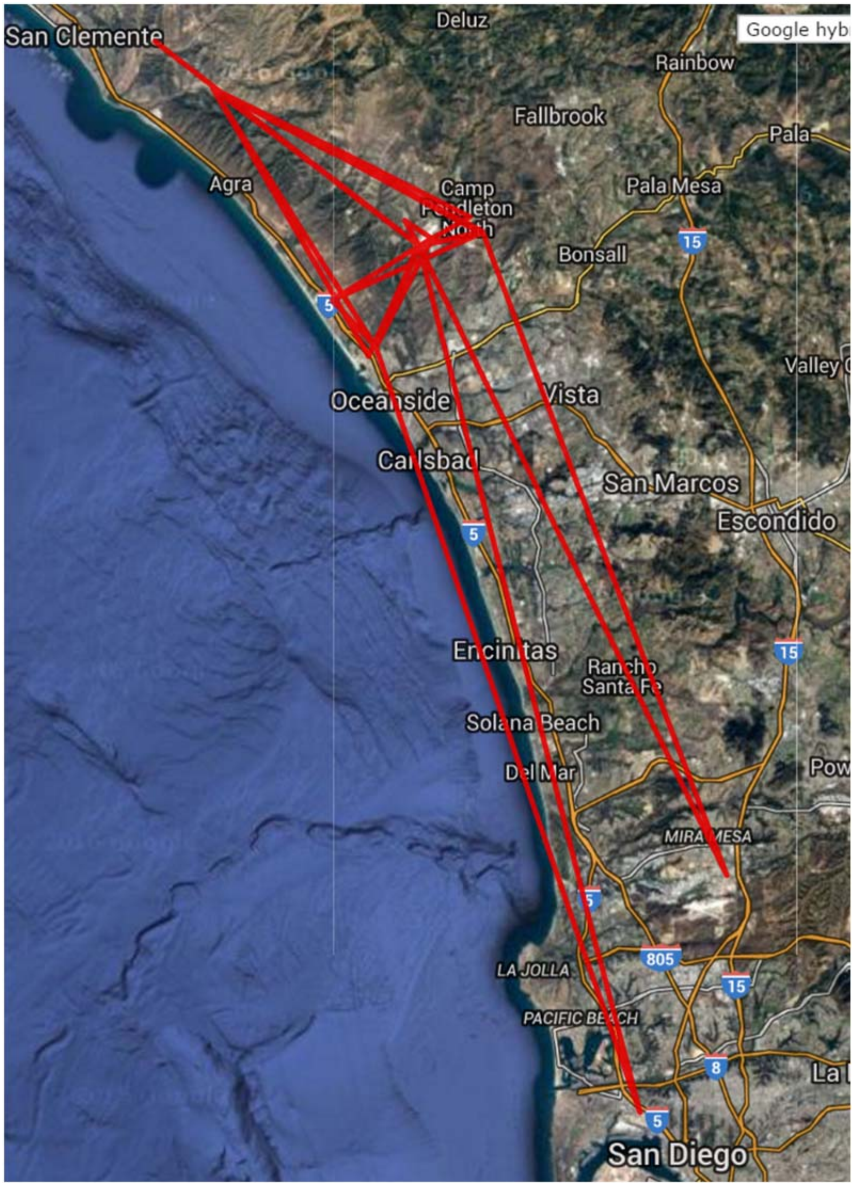
Table 17. Statistical Analysis of Vans by Fuel Type. Source: Mortlock, Whittaker, & Roberts (2016).

| Fuel Type | Quant. | Average MPG | Average Miles per trip | Average Miles per Day Utilized | Minimum Miles per Day Utilized | Median Miles per Day Utilized | Maximum Miles per Day Utilized | Average Yearly Miles |
|---|---|---|---|---|---|---|---|---|
| Diesel | 31 | 8.03 (1) | 22.80 (10) | 73.08 (11) | <1 mile (11) | 46.87 (11) | 468.0 (11) | 8806 (17) |
| Gasoline | 2 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |
| E85 FF | 12 | NO DATA | 5.53 (5) | 35.81 (5) | <1 mile (5) | 35.46 (5) | 92.8 (5) | 6920 (9) |
| Diesel Hybrid | 3 | NO DATA | 27.37 (3) | 122.64 (3) | <1 mile (3) | 122.23 (3) | 436.0 (3) | NO DATA |
| Electric | 2 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | 886 (1) |
| Unknown | 2 | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA | NO DATA |

Numbers in parenthesis indicate the quantity of vehicles for which data was available for analysis.

#### a. *Data Visualization*

Of our data set, only one van had Network Fleet stop detail telematics data available, located at Camp Pendleton. As shown in Figure 28, the van appears to travel primarily to and from Pendleton South, Pendleton North, Miramar, and San Diego.




Fuel Type: Diesel    Average Miles per Day Utilized: 44

Figure 28. Van G820211H Data Visualization. Source: Mortlock, Whittaker, & Roberts (2016).

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# IV. ALTERNATIVE FUELS

The Energy Policy Act of 1992, passed on October 24 by the 102nd Congress, is a key piece of federal legislation that defines what constitutes an alternative fuel. The act aimed to reduce America's dependence on petroleum based fuel products, as well as provide regulatory guidance to federal agencies to begin procurement of AFVs and their associated infrastructure. It also designated the Environmental Protection Agency the authority to maintain and update the list of authorized alternative fuels under this Act.

The Act defines alternative fuels as

- methanol, denatured ethanol, and other alcohols
- mixtures containing 85 percent methanol, denatured ethanol, and other alcohols with gasoline or other fuels
- natural gas
- liquefied petroleum gas
- hydrogen
- coal-derived liquid fuels
- fuels derived from biological materials
- electricity

Additionally, the Act states that an AFV could be a vehicle with a dedicated alternative fuel source or a dual fuel source (e.g., hybrid electric) and encouraged a diversified portfolio of each.

Petroleum accounts for 92 percent of the fuel used in the transportation sector as shown in Figure 29. In meeting the statutory requirements and SECNAV goals previously outlined, the DON aims to create a more diversified energy portfolio in its NTV fleet, as well as reduce the dependency on petroleum in this sector while meeting GHG reduction requirements.

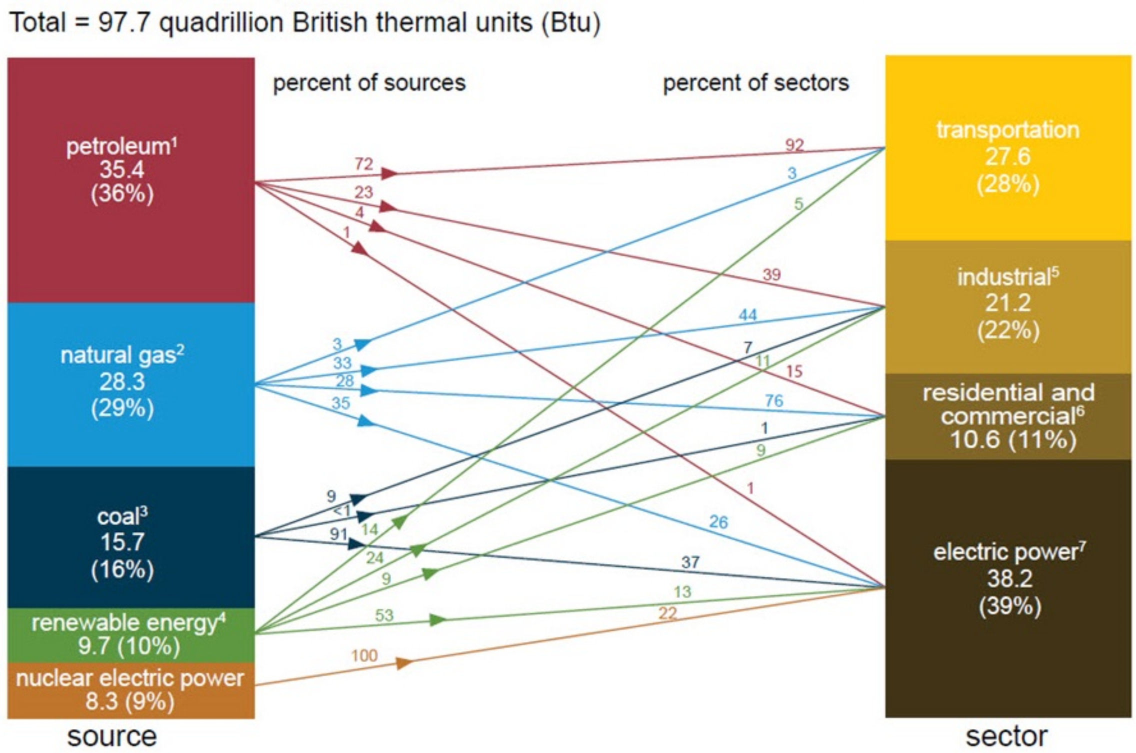



Figure 29. U.S. Primary Energy Consumption by Source and Sector, 2015.
Source: U.S. Energy Information Administration (2016c).

## A. TYPES

This chapter explores six alternative fuel types with the purpose of determining which AFV technologies are market ready for use in replacing the DON's NTV fleet. The different technologies are weighed against each other based on technological maturity, their contributions to GHG emission reduction, the maturity of their market and associated costs.

### 1. Electric

Electric vehicles in this study are broken into two general types. An electric vehicle (EV) is a dedicated alternative fuel technology. The vehicle is completely powered by a battery and is recharged at an electrical source as needed. A hybrid electric vehicle (HEV) is a duel fuel alternative fuel technology. The HEV has a few different varieties, but essentially uses an internal combustion engine part of the time and a battery source part of the time. The battery can be recharged through plugging into an electrical source when not in use, or can be charged by the engine and through regenerative braking technology.

Some advantages of EVs and HEVs come from their decreased use of petroleum as a source of energy, as well as their contribution to GHG reduction goals. HEVs provide higher fuel economies than their dedicated fossil fuel alternatives. Additionally, improvements in technology, battery storage, and transportation regulations are projected to bring EV and HEV prices down and their fuel efficiencies up over the next few decades as shown in Figure 30.

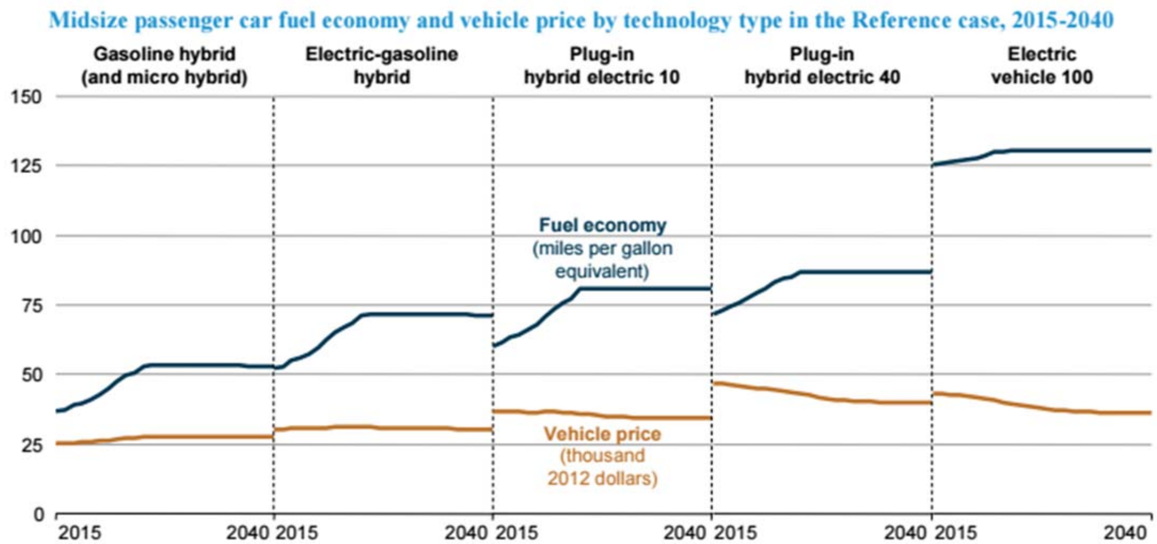



Figure 30. Gasoline versus Electric Vehicle Fuel Economy & Price. Source: U.S. Energy Information Administration (2015).

### *a. GHG Emissions*

All EVs and HEVs produce less CO2 than traditional fossil fuel vehicles. While operating on electricity they actually produce zero tailpipe emissions. That said, one must consider the source of electrical generation when attempting to quantify the reduction in GHG emissions an EV or HEV offers (U.S. Department of Energy, n.d.d). In areas of the country where electrical generation depends heavily on coal or other fossil fuels, EVs and HEVs will have less GHG reduction benefits. Since the majority of the fleet in this study resides in the state of California, Figure 31 illustrates the advantages of an EV or HEV both in the state and in comparison to the national average. It also shows the relative portfolio of electrical sources in each case. Overall, electric vehicles on the national average produce 50 percent or less GHG emissions than their gasoline alternatives.

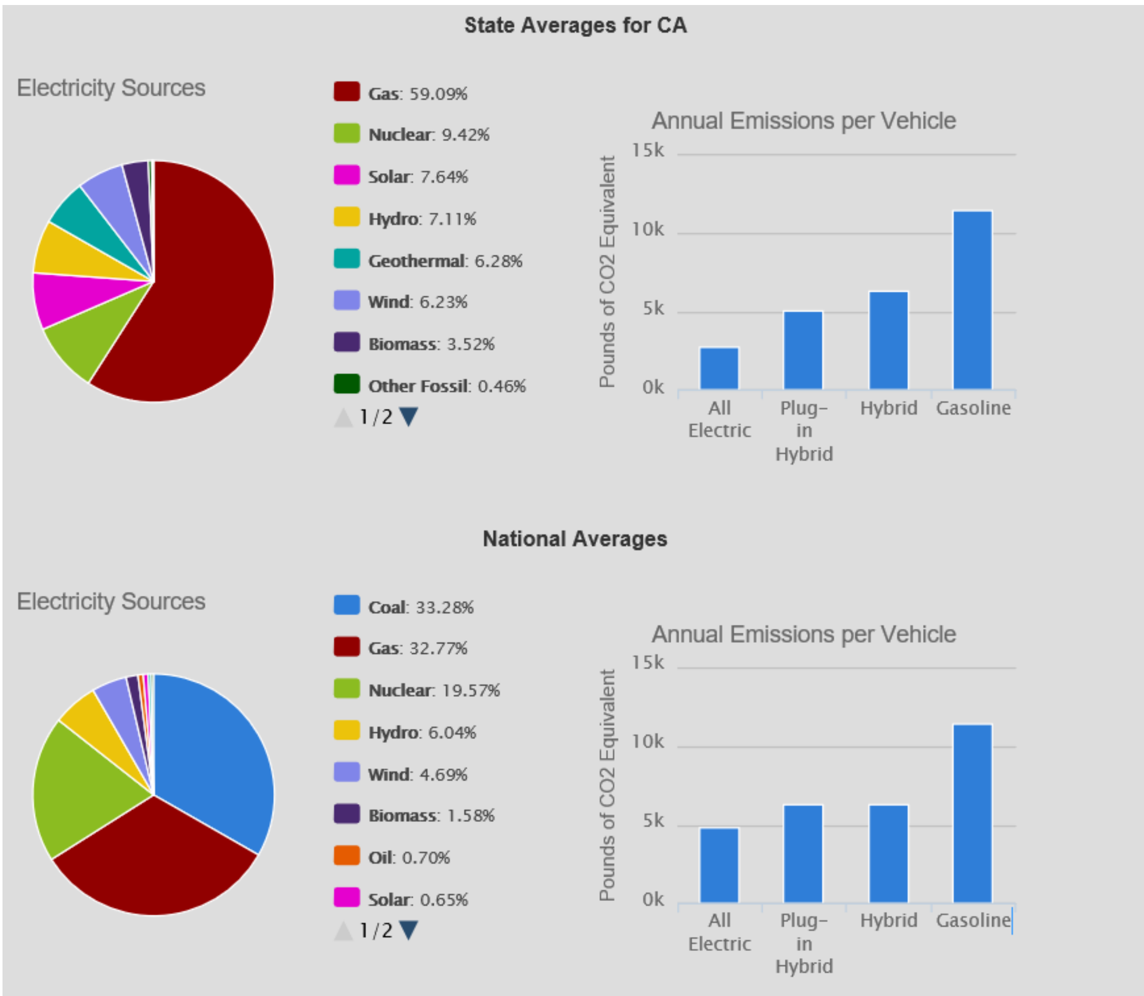



Figure 31. Electricity Sources and Vehicle Emissions—U.S. versus California. Adapted from U.S. Department of Energy (n.d.d).

#### *b. Cost*

While the operating cost of an EV or HEV is less than a dedicated fossil fuel alternative, the purchase price of an electric vehicle can often times be higher. The difficulty in definitively stating the purchase premium of an EV or HEV lies in the different varieties of makes and models available. For example, an electric passenger vehicle can cost anywhere between $25,000 and $125,000 depending on the make, model, and vehicle finishes. Any analysis of a purchase premium must weigh a particular electric vehicle against its closest fossil fuel alternative, shown later in Chapter V.

However, when looking at the operating costs of an electric vehicle, it is much easier to see the savings an electric vehicle provides. Gasoline and diesel prices have shown to be extremely volatile over the last several decades. Electricity rates, however, have proven to be much more stable. Figure 32 illustrates both the premium drivers of fossil fuel vehicles pay over an electric alternative as well as the volatility the price of gasoline offers versus the electric gallon equivalent.

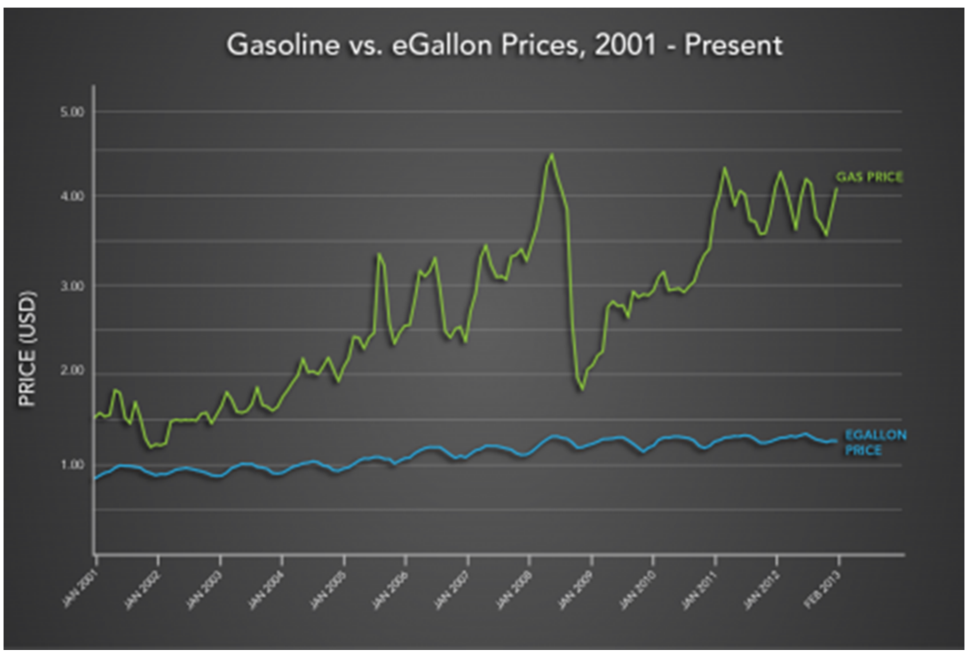



Figure 32. Gasoline versus Electricity (eGallon) Prices.
Source: Leistikow (2013).

To provide a cost per mile for driving an electric vehicle versus a gasoline alternative, the Idaho National Laboratory’s Advanced Vehicle Testing Facility provided Figure 33 showing the costs per mile of an electric vehicle versus a gasoline alternative. Since the average price of electricity in the United States averaged over the last 14 years is about $0.11 per kilowatt-hour (kWh), an EV or HEV is cheaper to operate per mile than a gasoline alternative (U.S. Energy Information Administration, n.d.a). This chart is helpful in identifying the breakeven costs between the two fuel sources or illustrating how low gasoline prices would have to go to provide equal per mile operating costs.

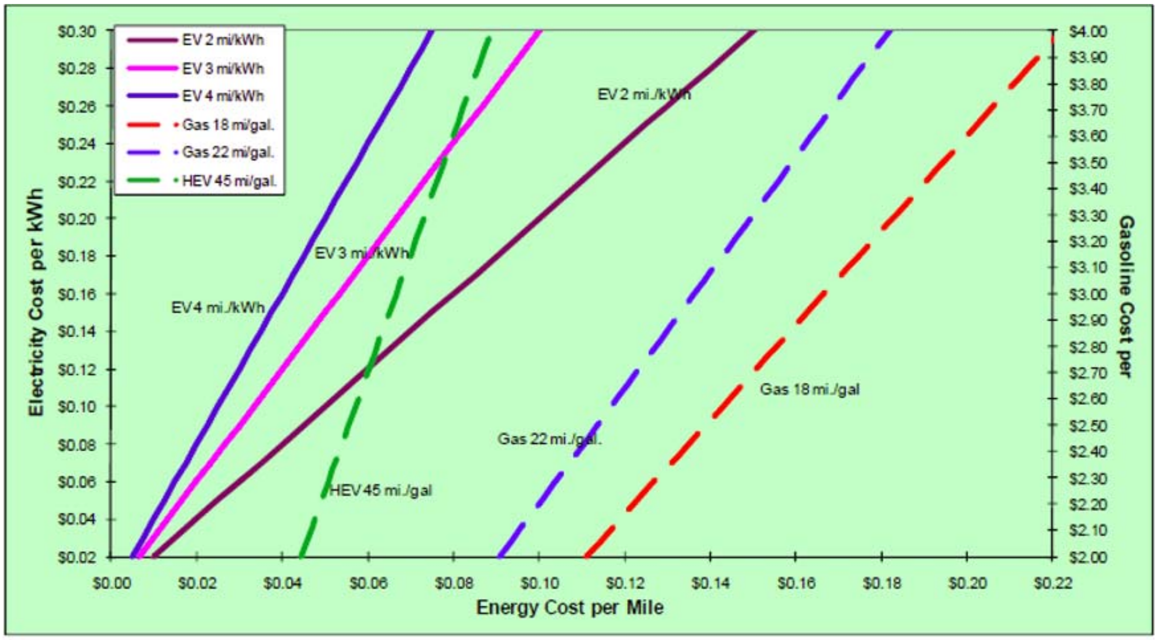



Figure 33. Energy Costs per Mile for Electric and Gasoline Vehicles. Source: Idaho National Laboratory (n.d.).

#### *c. Market*

The electric vehicle market is a rapidly growing sector. Public law, along with federal and state incentives have helped bolster the EV and HEV market. Additionally, battery storage technology is helping to bring the costs of owning an electric vehicle considerably down (U.S. Department of Energy, n.d.d). Given the trends in this market and relative availability of HEV and EV alternatives, these vehicles provide great benefit to the DON in both reducing their GHG emissions, but primarily in helping them meet their alternative fuel goals.

Additionally, a number of companies have been successful in retrofitting dedicated gasoline or diesel fueled vehicles into HEVs by installing battery capacity, regenerative braking technology, and software upgrades. This can prove to be a cost effective way of increasing fuel efficiency and transitioning a dedicated fossil fuel vehicle into a dual fuel alternative vehicle where the purchase premium for these vehicles does not provide the financial incentive necessary for replacing the existing vehicle.

### 2. Biodiesel

Biodiesel is a fuel produced domestically in the United States and made from vegetable and animal products, as well as recycled restaurant grease. Pure biodiesel, or B100, is used in the same manner as petroleum based diesel in compression-ignition engines (U.S. Department of Energy, n.d.c). Biodiesel is often blended with petroleum diesel to help increase alternative fuel use as well as improve its environmental impacts. Most diesel in the United States is B5, or contains a five percent biodiesel blend.

The advantages of low concentrate biodiesel such as B5 and B20, is that it can often be used in standard diesel engines without requiring any engine modifications. While the energy density is less than pure diesel, the Alternative Fuels Data Center of the U.S. Department of Energy has reported that it is often negligible and results in similar fuel economy. The issue with using B20 or other lower concentrate blends is with the vehicle manufacturer and the potential void of warranty if using blends higher than five percent.

Government regulation and mandates have provided the necessary impetus in the growth of the biodiesel market. Figure 34 illustrates the biodiesel targets over time in response to both demand and regulatory requirements.

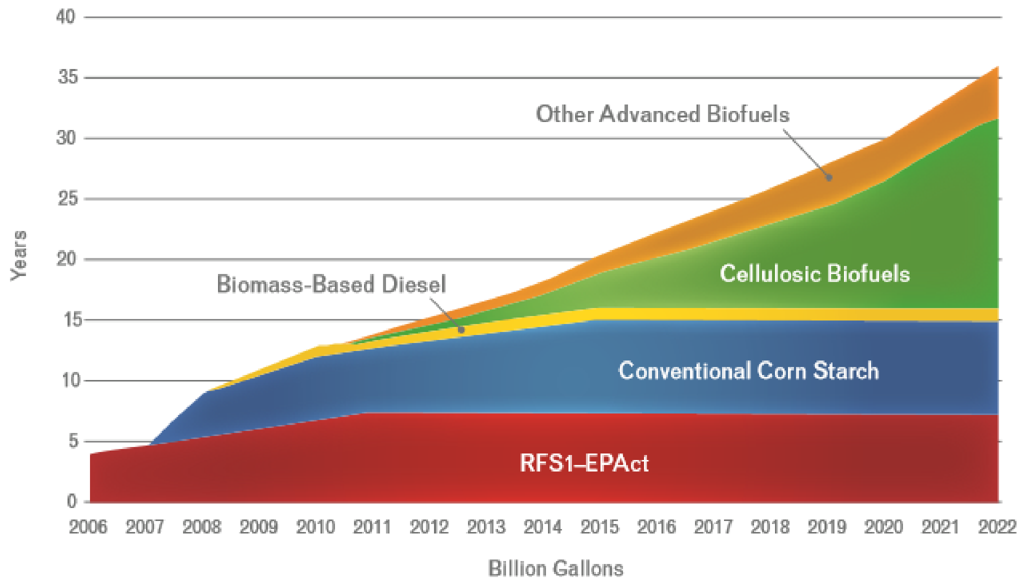



Figure 34. Biodiesel Production Targets through 2022. Source: The Biomass Research and Development Board (2012).

### *a. GHG Emissions*

Diesel burning vehicles manufactured after 2010 are required to meet the same emissions standards, regardless of the blend. Selective catalytic reduction technology in these vehicle types produce many of the cleanest combustion engines. Because of this, emissions from diesel and biodiesel blends are roughly equivalent (U.S. Department of Energy, n.d.b).

Biodiesel, however, reduces GHG emissions during fuel production when soybean or other feedstock absorbs CO2 during growth. GHG emissions generated by combustion are offset by this. Figure 35 shows pure biodiesel from different sources in comparison to petroleum diesel in terms of GHG emissions.

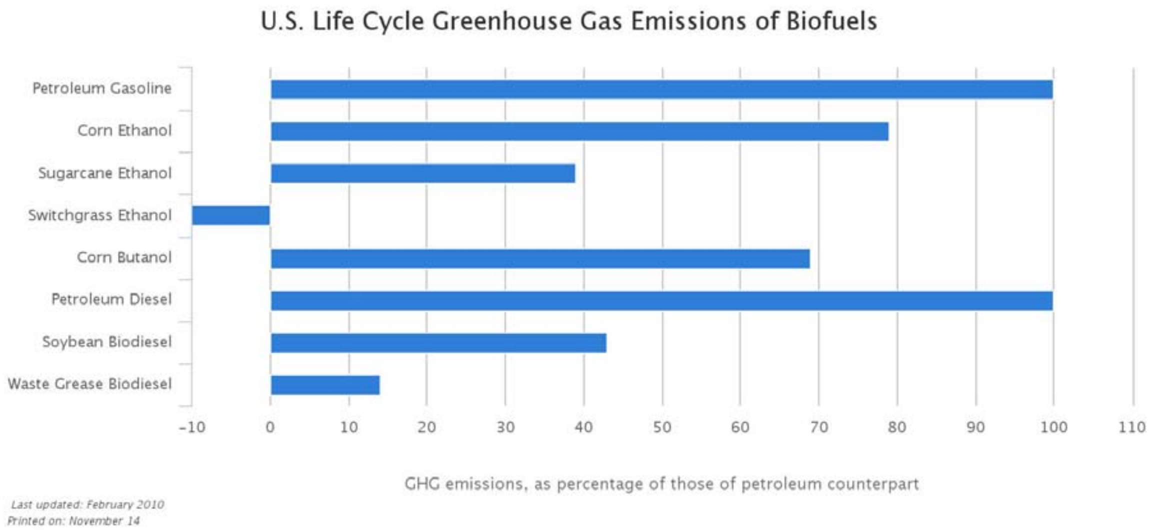



Figure 35. GHG Emissions of Biofuels versus Petroleum Fuels.
Source: Environmental Protection Agency (2010).

***b. Cost***

Fuel cost for vehicles that operate on biodiesel are broken into two general categories, low concentrate biodiesel and high concentrate biodiesel.

(i) Low Concentrate Biodiesel (B20)

B20 is a biodiesel blend that is 20 percent biodiesel and 80 percent petroleum diesel. The price of B20 closely tracks petroleum diesel prices as shown in Figure 36.

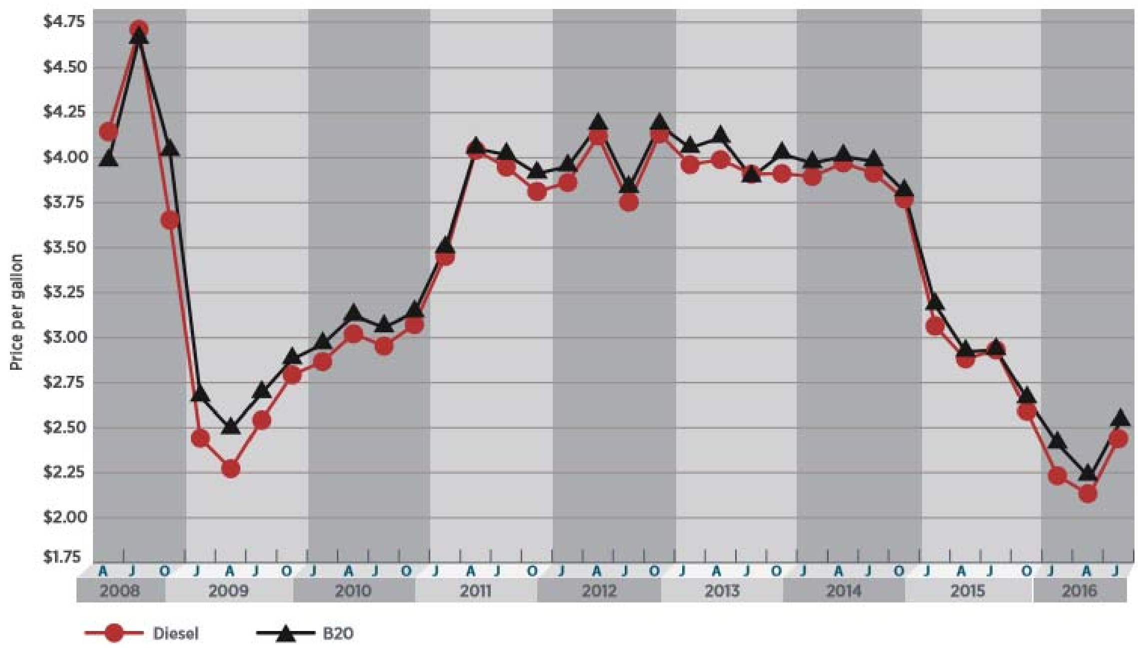



Figure 36. B20 versus Petroleum Diesel Fuel Prices.
Source: U.S. Department of Energy (2016).

(ii) High Concentrate Biodiesel (B99/B100)

B99/B100 biodiesel is more difficult to find and requires vehicles specifically manufactured to operate on pure biodiesel. The cost of B99/B100 tracks slightly higher per gallon than petroleum diesel as shown in Figure 37.

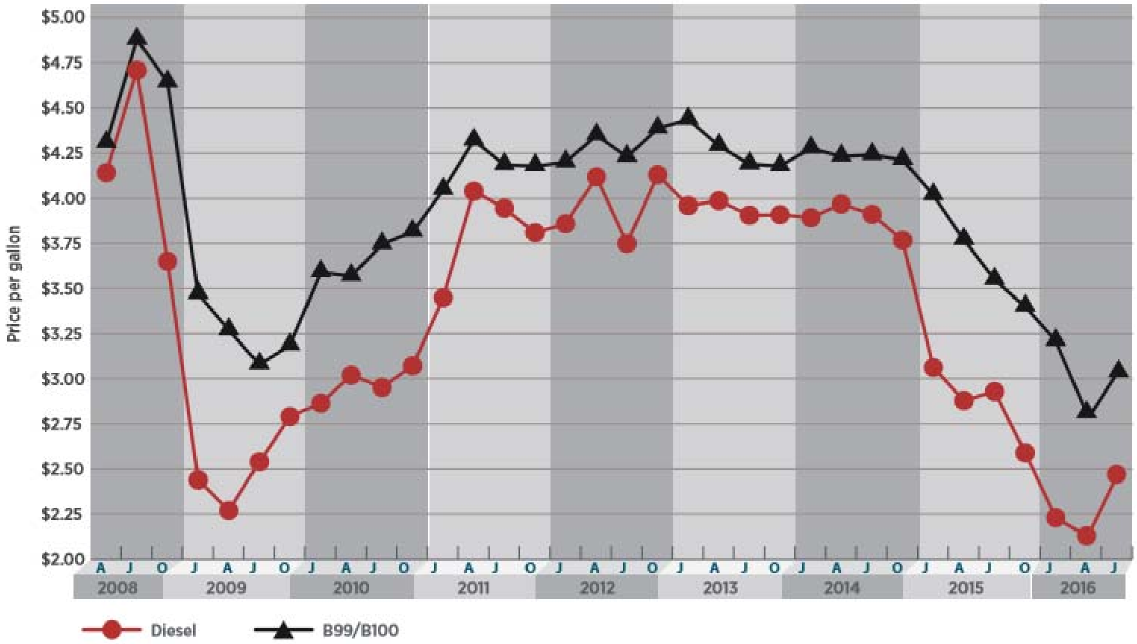



Figure 37. B99/B100 versus Petroleum Diesel Fuel Prices.
Source: U.S. Department of Energy (2016).

#### *c. Market*

The biodiesel market is driven primarily by government subsidy and regulation. Use of B20 in newly manufactured vehicles pose a potential warranty risk, but requires no engine modification. However, use of B99/B100 fuel requires a vehicle designed specifically for that dedicated fuel source. This market is in its infancy with few manufacturers providing alternative vehicles at a high premium and limited infrastructure distribution. Figure 38 shows the price differentials by state, with un-highlighted states lacking the fueling infrastructure to support B99/B100 vehicles.

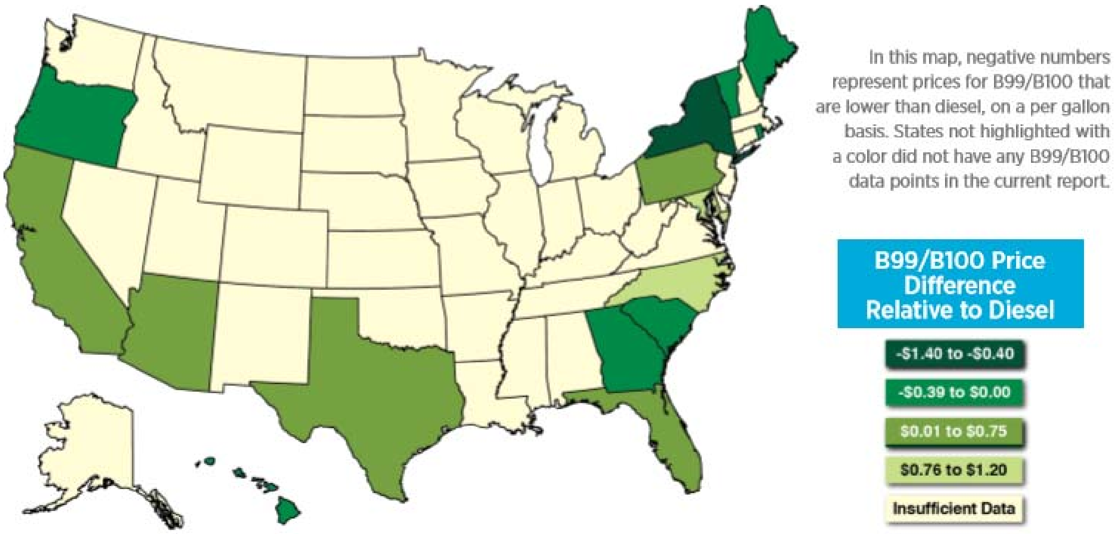



Figure 38. B99/B100 Price Differential and Availability. Source: U.S. Department of Energy (2016).

Given this information, the DON could benefit from using low concentrate biodiesel in their current petroleum diesel vehicles to achieve an increase in their use of alternative fuels and a credit in their reduction of GHG emissions. However, in doing so, the DON assumes risk on those vehicles still under manufacturer's warranty. Additionally, depending on the region and mission of an activity, the use of B99/B100 lacks a robust manufacturer's market and fuel distribution network.

### 3. Ethanol

Ethanol is a renewable fuel made of biomass material. Nearly all gasoline in the United States is blended with about 10 percent ethanol (E10) (U.S. Department of Energy, n.d.e). Flexfuel (E85) can be used in vehicles designed to operate on gasoline-ethanol blends that contain up to 83 percent ethanol. While ethanol and gasoline-ethanol blends provide an alternative source for fuel and a reduction in GHG emissions per gallon, its energy content is lower than gasoline. This results in a less fuel-efficient vehicle and higher fuel costs than a traditional gasoline alternative. However, as shown in Figure 39, ethanol demand has kept up with increasing supply over the last fifteen years, indicating an increased demand for ethanol products.

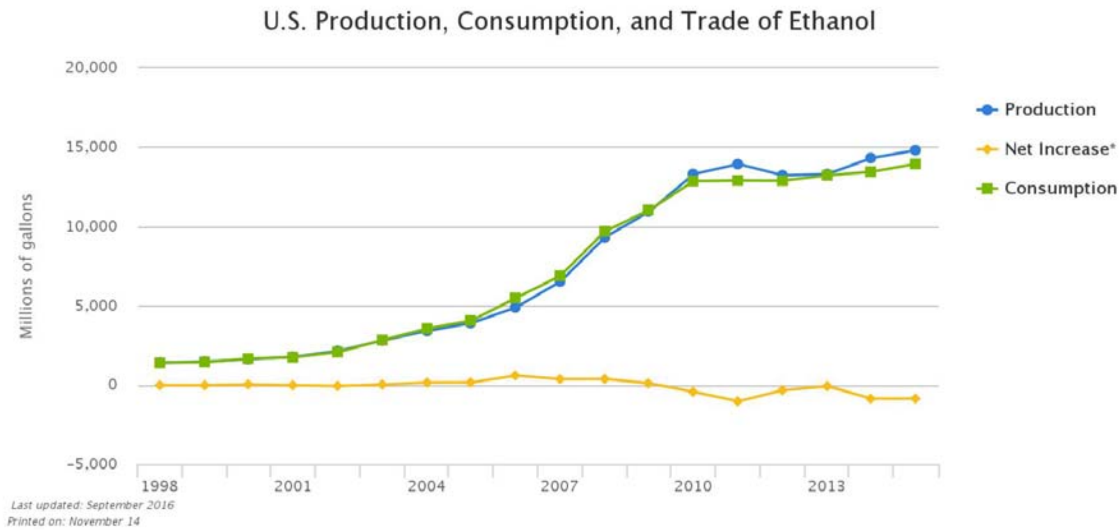



Figure 39. U.S. Production, Consumption, and Trade of Ethanol.
Source: U.S. Energy Information Administration (2016d).

### *a. GHG Emissions*

Figure 35, shown in a previous section, illustrated the benefits ethanol provides in terms of GHG emission reduction quotas. The actual GHG emission reduction varies on the type of biomass used to create the ethanol and the level of concentrate in gasoline-ethanol blends. Regardless, ethanol provides substantial savings in terms of GHG emissions.

### *b. Cost*

The use of E10 as standard gasoline has become common throughout the United States. E10, while providing benefits, is not considered an alternative fuel. Flex fuel, or E85, however is. Additionally, new vehicles are being designed to be able to operate on E85 or gasoline, providing the opportunity for users to buy alternative fuel without making engine modifications or requiring a specific engine to run it on. That said, the decreased fuel economy coupled with the increased price over gasoline, as shown in Figure 40, result in higher overall operating costs for a typical user, holding usage constant.

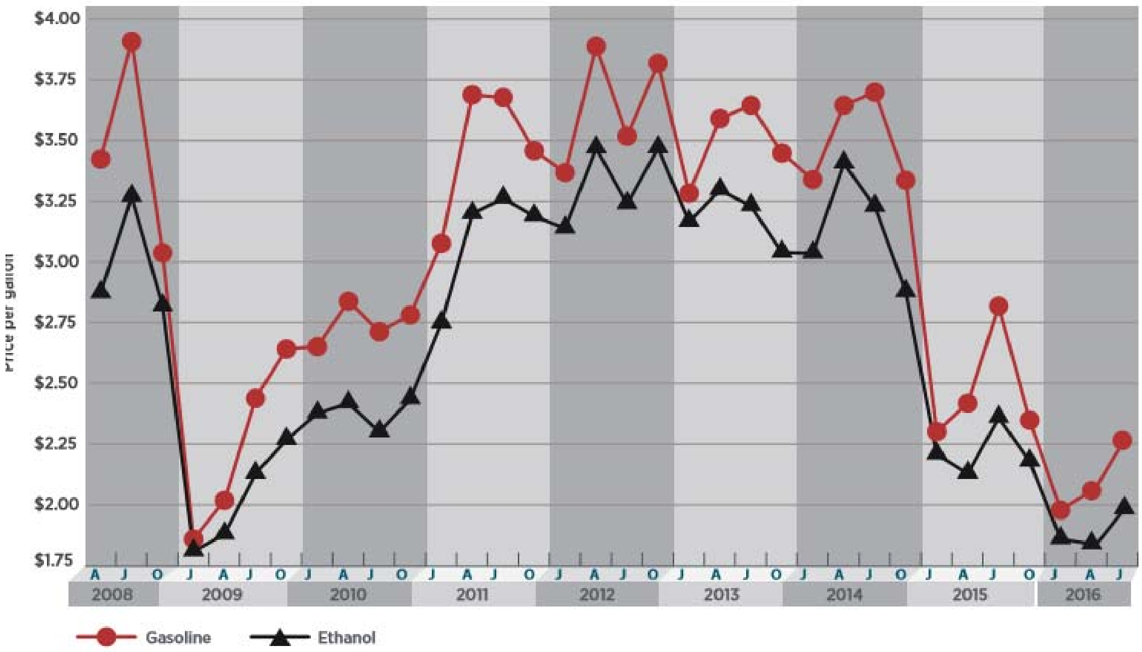



Figure 40. Historical Ethanol versus Gasoline Fuel Prices.
Source: U.S. Department of Energy (2016).

#### *c. Market*

The use of ethanol and the manufacturing of vehicles that run on ethanol or ethanol-gasoline blends has become commonplace in the United States. Additionally, the Navy has invested heavily in E85 distribution infrastructure at their base locations. Additionally, E85 vehicles make up the majority of alternative fueled vehicles on the market today. Figure 41 shows the supply of flex fuel vehicles in comparison to all other alternatives over a ten-year span.

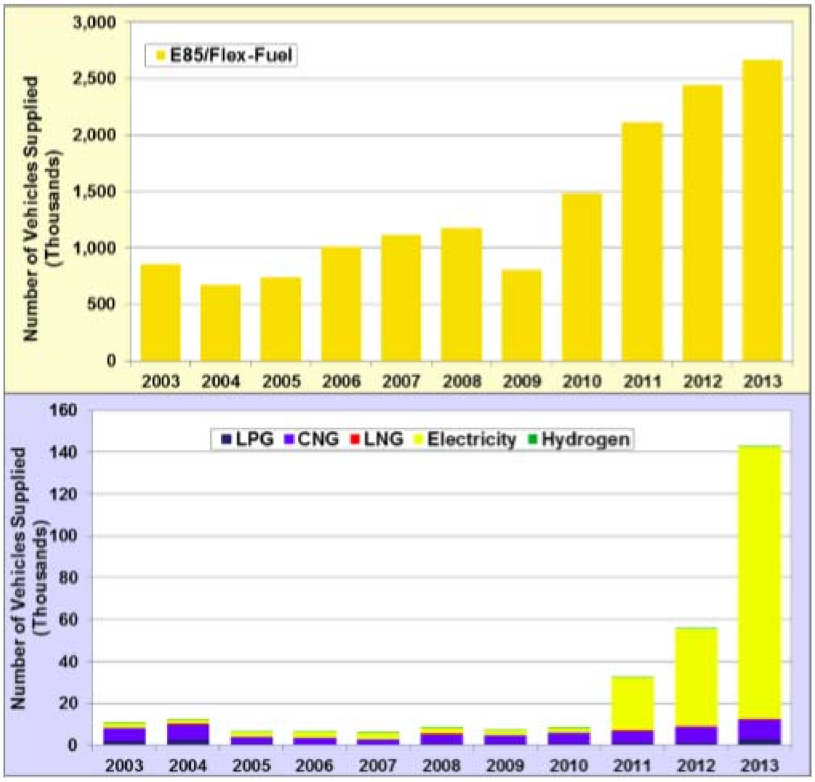



Figure 41. Ethanol versus Other Alternative Fuel Vehicles Supplied. Source: Oak Ridge National Laboratory (2015).

The investment the DON, as well as MCIWEST, has made in the use of E85 vehicles, illustrates that E85 is both a viable alternative and has a market that makes it attractive for use. This report however will not focus on the conversion of vehicles to E85 given that the methodology for doing so is well understood and currently in use by the DON and fleet managers.

#### 4. CNG

CNG as an alternative fuel is attractive primarily for its cost per gallon equivalent, its domestic availability, and its contributions to GHG emission reduction targets. Although a fossil fuel, they are considered an alternative fuel by the Energy Policy Act of 1992 (U.S. Department of Energy, n.d.g). Natural gas lends itself to heavier class vehicles that travel high mileage with large compressed storage space and centrally fueled fleets. This makes consideration for use of CNG for medium- and heavy-duty replacement attractive for DON’s NTV fleet.

### *a. GHG Emissions*

Argonne National Laboratory's GREET model estimates a six to 11 percent reduction in GHG emissions over the life of a CNG vehicle compared to a gasoline alternative. CNG is a cleaner burning fossil fuel than gasoline. However, leaked CNG provides more harmful GHG emissions making fuel storage and leakage containment an important issue for CNG manufacturers.

### *b. Cost*

CNG fueling infrastructure costs play an important role in determining the cost effectiveness of replacing a fleet of traditionally fueled vehicles with CNG. A detailed analysis of this will be explored in the next chapter.

However, CNG fuel costs have historically tracked lower than gasoline or diesel over the last several years as shown in Figures 42 and 43. Additionally, CNG prices are more stable over the long term than gasoline or diesel providing fleet managers less uncertainty in operating costs from year to year.

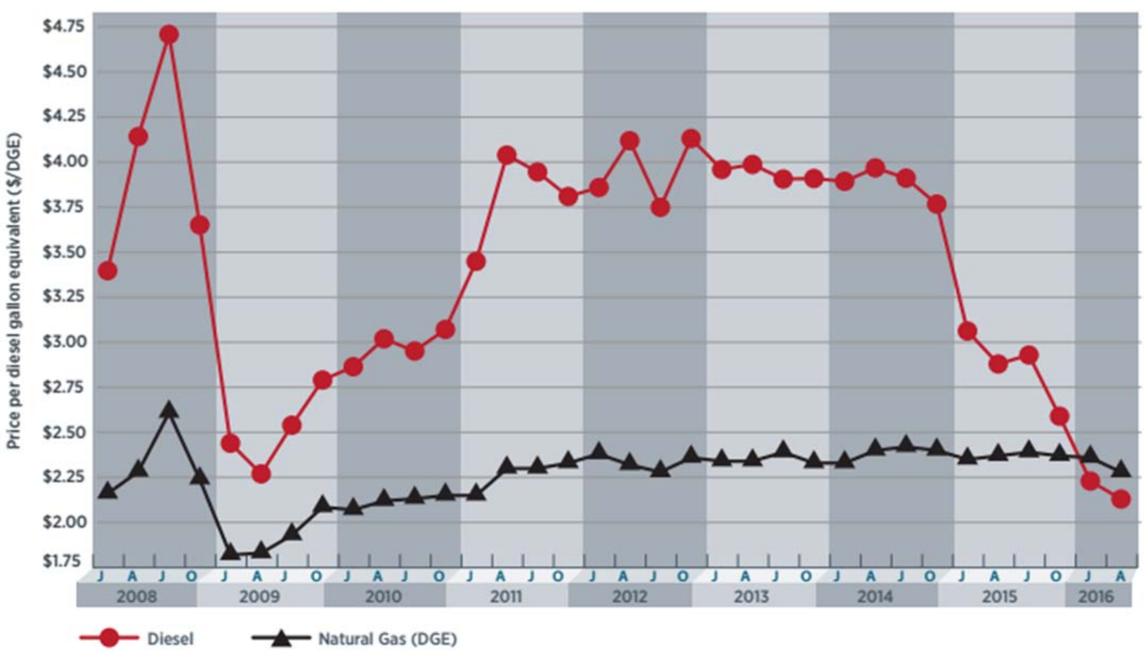



Figure 42. Historical CNG versus Diesel Fuel Price.
Source: U.S. Department of Energy (2016).

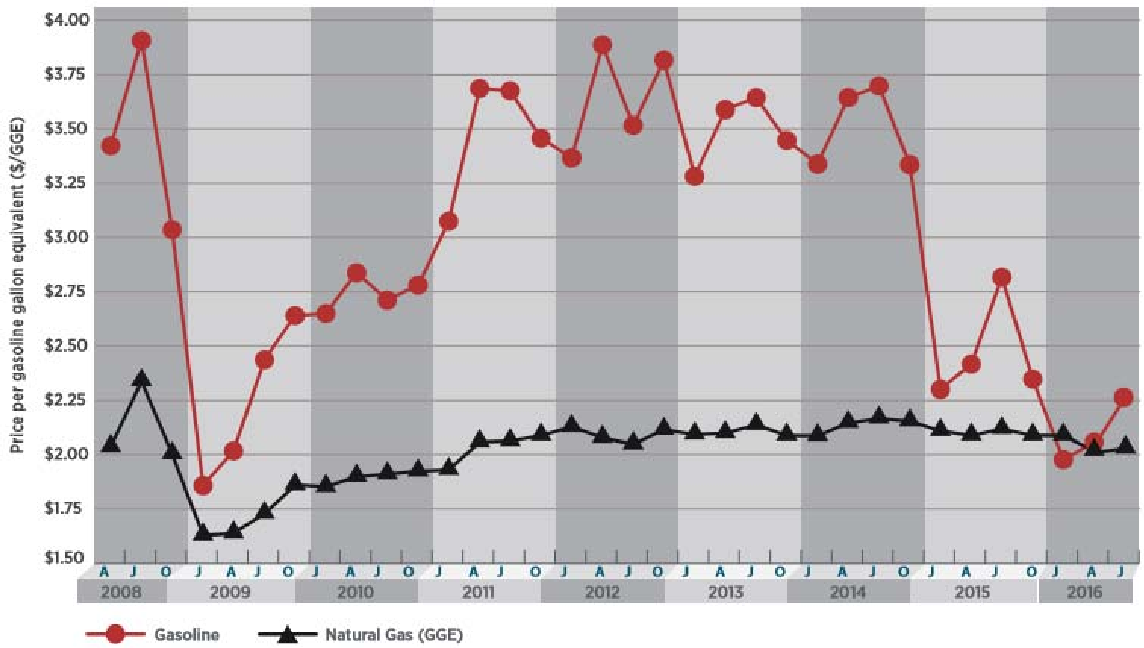



Figure 43. Historical CNG versus Gasoline Fuel Price.
Source: U.S. Department of Energy (2016).

#### *c. Market*

Municipalities, freight and parcel organizations, and government agencies are investing heavily in natural gas technology and infrastructure. MCIWEST SW region has three of its seven bases with available CNG fueling infrastructure. It's low, stable fuel cost, cleaner burning properties, domestic availability, and classification as an alternative fuel have made it an attractive choice for organizations that travel higher miles with larger centrally fueled fleets. Additionally, easy conversion from gasoline or diesel to CNG in larger vehicles have made it more economical for converting capital assets with many years of remaining useful life. Additionally, as shown in Figure 44, most states now have natural gas fueling stations, making it more economical for organizations to use.

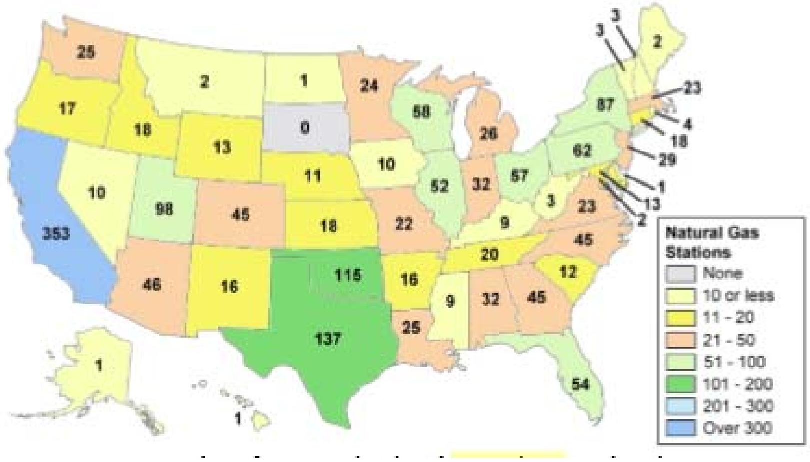



Figure 44. Number of Natural Gas Stations by State.
Source: Oak Ridge National Laboratory (2015).

### 5. Hydrogen

The Energy Policy Act of 1992 defines hydrogen as an alternative fuel. Hydrogen is a domestically produced fuel used in vehicles with fuel cell technology. Hydrogen used to power a fuel cell with an electric engine offers the benefits of an emission free technology. Additionally, hydrogen is widely available in water, and when used in a fuel cell, releases only water vapor and warm air as its by-product (U.S. Department of Energy, n.d.f).

Fuel cell technology and hydrogen fueling infrastructure is however limited in its availability. While a hydrogen fuel cell vehicle is two to three times more efficient than an internal combustion engine in its use of energy, the energy density of hydrogen is significantly lower than gasoline or other petroleum products. This creates a hydrogen storage problem that vehicle manufacturers are working to resolve.

#### *a. GHG Emissions*

As stated previously, hydrogen fuel cell technology offers the benefits of a domestically produced alternative fuel with zero tailpipe emissions when coupled with an electric engine. Extracting hydrogen form water, however, is an energy intensive method of producing hydrogen. More often, hydrogen is extracted from natural gas. Due to this, the well-to-wheel emissions for hydrogen vehicles is not zero when including extraction, transportation, and storage of hydrogen fuel, as shown in Figure 45.

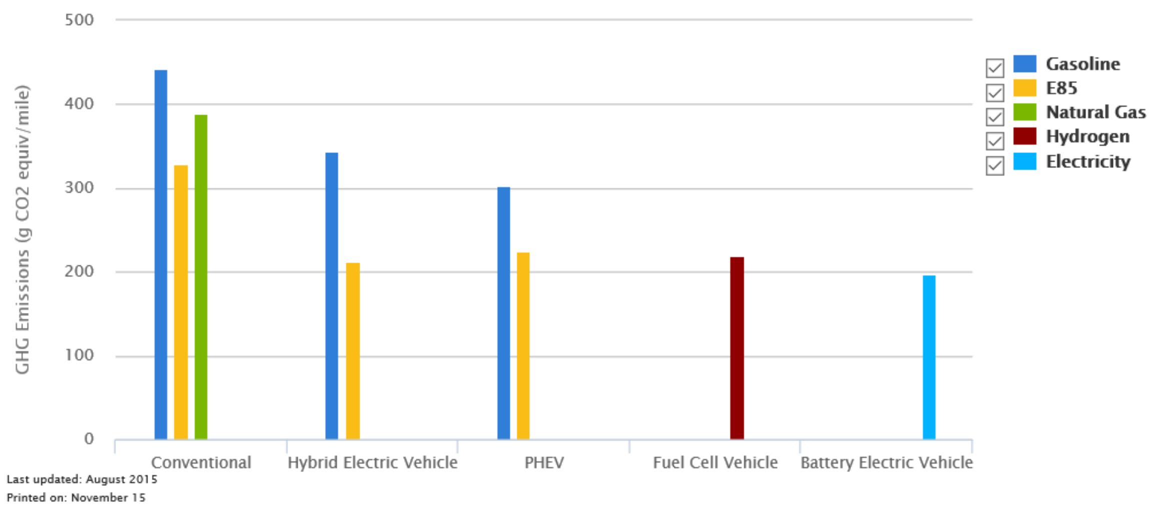



Figure 45. GHG Emissions by Fuel Type. Source: U.S. Department of Energy (2015).

### *b. Cost*

Currently, the fuel cell vehicle is in its infancy in production and cannot compete with standard petroleum or alternative fueled competitors. Figure 46 shows that while companies have made progress in reducing vehicle costs; they still have not met targets necessary to be competitive in the marketplace of roughly $30/kWnet.

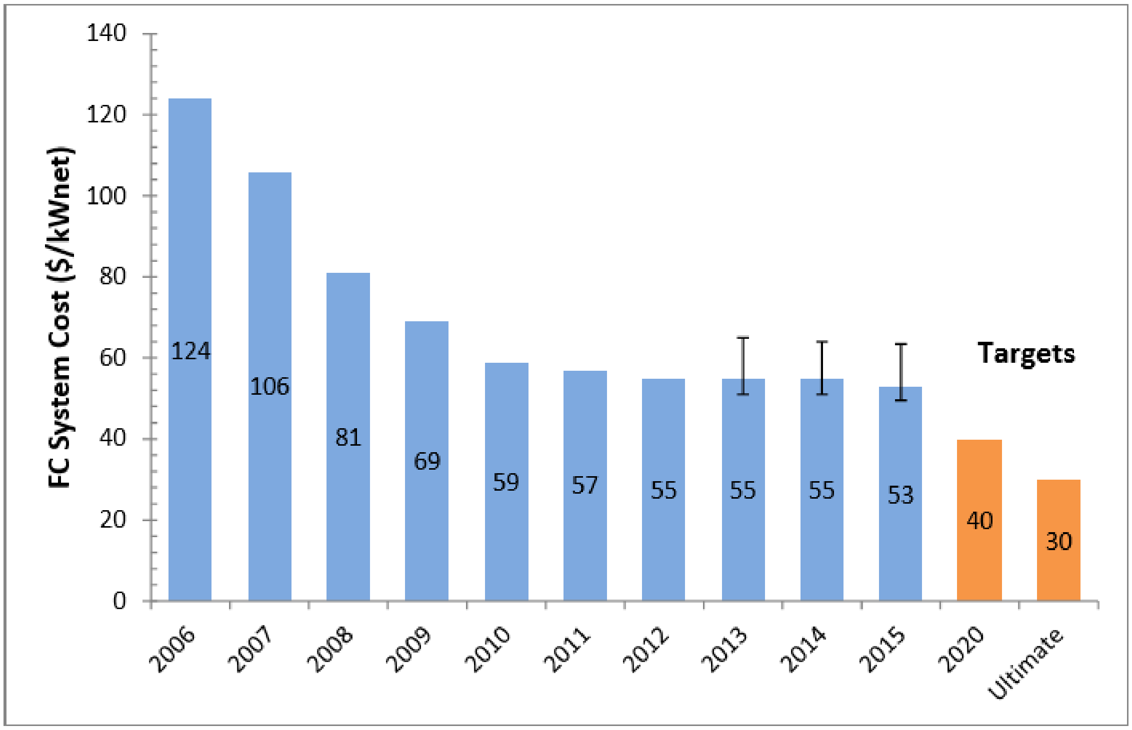



Figure 46. Hydrogen Fuel Cell Vehicle Cost Analysis. Source: Marcinkoski, Spendelow, Wilson, & Papageorgopoulos (2015).

In addition to increased purchase cost, fueling costs are roughly twice as high in fuel cell vehicles when compared to gasoline alternatives.

### *c. Market*

While many companies are investing in fuel cell technology, the hydrogen fuel cell market is still in its infancy, especially concerning medium- and heavy-duty vehicles. Figure 47 shows the medium- and heavy-duty models that are available as of 2016. These vehicles come with a high purchase premium, as previously discussed, as well as limited fueling infrastructure availability, as shown in Figure 48.

| Manufacturer | Model | Category |
|---|---|---|
| **Electric** | | |
| Balqon | Mule M150 | Vocational/Cab Chassis |
| Balqon | XE-20 | Tractor |
| Balqon | XE-30 | Tractor |
| Boulder Electric Vehicle | DV-500 Delivery Truck | Step Van |
| BYD (Build Your Dream) | 40 ft. Transit Bus | Transit Bus |
| BYD (Build Your Dream) | 60 ft. Transit Bus | Transit Bus |
| Capacity Trucks | HETT | Tractor |
| DesignLine Corp. | Eco-Smart 1 | Transit Bus |
| Electric Vehicles International | EVI-MD | Vocational/Cab Chassis |
| Electric Vehicles International | WI EVI | Step Van |
| Enova Systems | Enova Ze Step Van | Step Van |
| GGT Electric | Electric | Vocational/Cab Chassis |
| Navistar-Modec EV Alliance | eStar | Step Van |
| New Flyer | Xcelsior | Transit Bus |
| Proterra | EcoRide BE35 | Transit Bus |
| Smith Electric Vehicles | Newton | Vocational/Cab Chassis |
| Smith Electric Vehicles | Newton Step Van | Step Van |
| Trans Tech | ETrans | School Bus |
| ZeroTruck | ZeroTruck | Vocational/Cab Chassis |
| **Hydrogen Fuel Cell** | | |
| Capacity Trucks | ZETT | Tractor |
| Ebus | EBUS22FC | Shuttle Bus |
| ElDorado National | Axess | Transit Bus |
| New Flyer | Xcelsior | Transit Bus |
| Van Hool | A300L Fuel Cel | Transit Bus |
| Vision Motor Corp. | Tyrano | Tractor |
| Vision Motor Corp. | ZETT | Tractor |

Figure 47. Hydrogen Fuel Cell Medium- and Heavy-Duty Vehicles in the Market.
Source: Oak Ridge National Laboratory (2015).

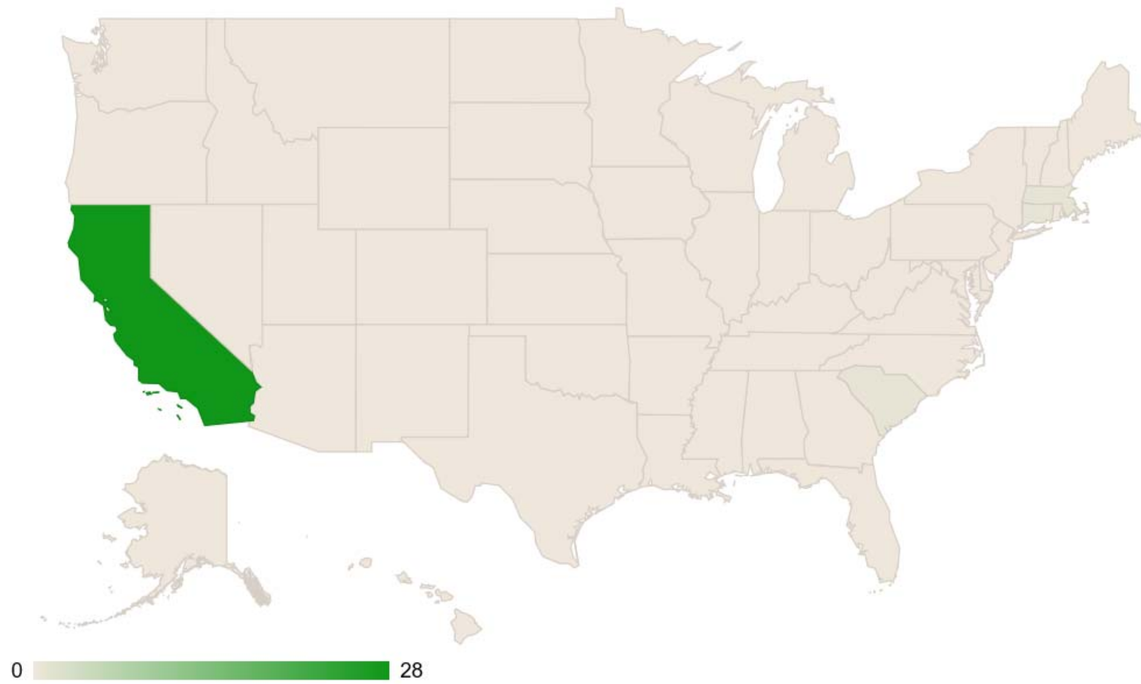



Figure 48. Hydrogen Fueling Locations by State. Source: U.S. Department of Energy (n.d.f).

While hydrogen fuel cell technology offers many future advantages, its market, infrastructure availability, and increased costs make it a poor candidate for analysis for this study. As infrastructure becomes more widely available and vehicle and fuel costs come down over the next decade, perhaps hydrogen fuel cell technology can be addressed later to help achieve DON goals.

### 6. Propane

Propane or liquid petroleum gas (LPG) is a by-product of natural gas or crude oil refinement (U.S. Department of Energy, n.d.h). Classified as an alternative fuel by the Energy Policy Act of 1992, LPG is attractive for use because of its domestic availability, contributions to GHG emission reduction, various incentives, and lower costs.

#### *a. GHG Emissions*

The Argonne National Laboratory predicts that vehicles that operate on LPG reduce GHG emissions by roughly 10 percent over the life of the vehicle. However, this heavily depends on the fuel source, vehicle type and vehicle age. While not as attractive as other alternative fuels in helping the DON achieve its emission reduction goals, it still provides a better alternative than its gasoline or diesel counterparts do.

#### *b. Cost*

LPG vehicles demand a high purchase premium over their gasoline or diesel counterparts. LPG fuel costs, however, have been traditionally lower than gasoline providing a relatively quick buy back period. However, as gasoline prices continue to decline in the United States, propane fuel becomes less and less an attractive option for buyers as show in Figure 49.

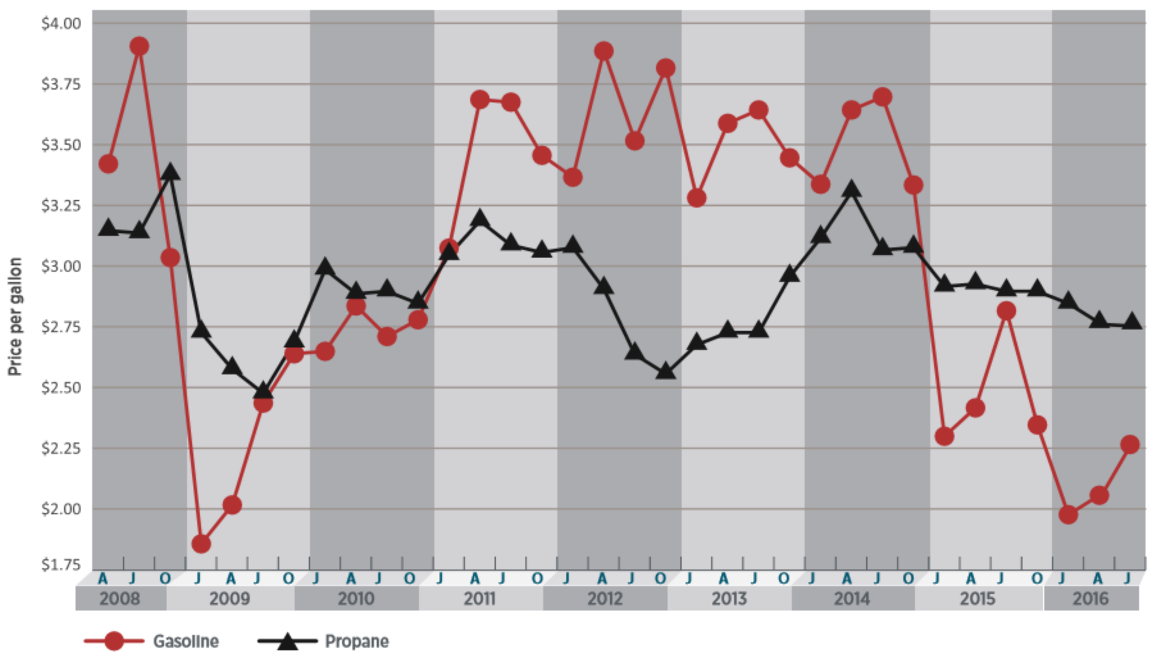



Figure 49. Historical LPG versus Gasoline Fuel Price. Source: U.S. Department of Energy (2016).

With LPG vehicles failing to become cost competitive from a purchase price and fueling perspective, its advantages lie in its ability to prolong engine life and lower vehicle maintenance costs due to its high octane rating and low contaminant characteristics (Mortlock, Whittaker, & Roberts, 2016).

### *c. Market*

LPG has been used in the transportation sector for many years. However, for many of the previously mentioned reasons, and because of competitive forces in the alternative fuel industry, its market has seen little growth and even decline over the last several years as shown in Figure 41.

While most states have propane-fueling stations, the number of new stations coming on line and the relative percentage of the market LPG vehicles have taken makes this technology less attractive for analysis.

## B. VIABLE ALTERNATIVES

In deciding which alternative technologies to model, it is critical that any proposed alternative have an abundance of market alternatives that meet the operational requirements of the DON. Additionally, this study weighed heavily both the availability and growth of infrastructure in the United States, and the costs associated with the proposed alternatives.

Given this, and the previous analysis of AFV technologies, it has been determined the battery electric, hybrid electric, and CNG technologies hold the greatest potential for the DON and MCIWEST SW region. The next chapter will address those technologies and the methodology by which fleet managers can use to determine if these AFV alternatives provide an attractive business solution to meet the DON goals.

# V. BUSINESS CASE METHODOLOGY

## A. ALTERNATIVE FUEL MODELS

### 1. CNG Methodology

Natural gas is a relatively cleaner burning fuel that is abundant and domestically produced. CNG is a fuel that has become popular within the transportation and logistics communities because of these qualities as well as its price stability when compared to petroleum fuels. Figures 42 and 43 (see pp 66–67) not only display the cost differential between diesel and CNG over time but also shows the price stability difference between the two.

To complete a cost comparison between CNG and petroleum we utilized the Vehicle Infrastructure and Cash-Flow Evaluation (VICE 2) model created by the National Renewable Energy Laboratory (NREL) (Mitchell, 2015).

VICE 2 uses many variables for tax, incentives, infrastructure and vehicles to assess the business case when considering CNG as a vehicle fuel. Additionally, it allows comparisons to be made between different acquisition and investment strategies. Finally, this model will provide visualizations of cash flow, fuel availability and GHG savings using sensitivity analysis.

A description of the model architecture and available inputs follow. Each data set has been updated with current data to support our analysis.

#### *a. VICE Model Parameters*

The VICE 2 model is divided into 6 sections in which inputs are required and are as follows:

(i) Project and Investment Type

There are two types of project types. The default, which is the first option, is a coupled CNG vehicle and infrastructure investment. The second option is for CNG vehicles only. Considering the region in which we researched (MICWEST) was comprised of seven Marine Corps bases (Camp Pendleton, Twentynine Palms, Miramar, Yuma, San Diego, Barstow and Bridgeport), three of which had CNG infrastructure already installed (Camp Pendleton, Yuma and Barstow). Because of the fact that infrastructure does exist within our entire base sample, we will evaluate Net Present Values with and without infrastructure.

Like project types, investment type is broken down into two options. The first option is vehicle and station coupled in which the VICE 2 model will automatically update infrastructure costs based on the type and amount of vehicles we enter. When taking into account infrastructure cost, we will use this option. The second option is vehicle and station decoupled. This eliminates the dependency of vehicles and infrastructure, and will be utilized when formulating NPV without considering infrastructure.

(ii) Tax Exemption Status

We assumed that Department of Defense vehicle fleet is not tax exempt.

(iii)Vehicle Data

**Vehicle Type (Base Fuel Used).** There are seven types of vehicle options to choose from: transit bus (Diesel), school bus (Diesel), trash truck (Diesel), shuttle bus (Gasoline), delivery truck (Gasoline), gasoline pickup truck and gasoline taxi.

**Incremental Cost.** Difference in cost between gasoline/diesel and CNG. Incremental costs are pre-determined within the VICE model and are based off information located at the Alternative Fuel Data Center (www.afdc.energy.gov) and Transportation Energy Data Book, Edition 31.

**Average Vehicle Miles Traveled (VMT – annual).** The VMT for our data set was gathered using telematics coming from five sources as described in Chapter III.

**Average Vehicle Life.** We will assume an average vehicle life of 15 years.

**Base Fuel Economy (MPG base fuel).** Information gathered through telematics are annotated in Tables 7 through 17. For Fire Trucks and Tractor Trailers we will assume a 6 MPG based on a market report from the Center for Transportation Analysis (Oak Ridge National Laboratory, 2015).

**Efficiency Loss.** Represents the expected difference in operating efficiency between CNG and gas/diesel with regard to a similar vehicle. Based on gathered telematics we will use a CNG increased efficiency rate of 12.5 percent.

**Attendants Needed.** This represents additional attendants needed if infrastructure is installed. We assumed zero because if we replace a petroleum-based vehicle with a CNG vehicle that would decrease the number of personnel needed at a gas station but increase the personnel needed for a CNG station at a 1:1 ratio.

(iv) Infrastructure, Fuels, Operations and Incentives

**CNG Station Salvage Value.** Salvage value for a CNG station is assumed to be 20 percent based on expert interviews conducted by NREL (Mitchell, 2015).

**Infrastructure Tax Credit Rate.** Considering our study deals only with DOD NTV MDV/HDV, we assumed all tax credits to be zero.

**Price of Gasoline, Diesel and CNG**. Based on the July 2016 alternative fuel price report conducted by the U.S. Department of Energy the price of gasoline, diesel and CNG are as follows (U.S. Department of Energy, 2016):

- Gasoline: $2.26
- Diesel: $2.46
- CNG: $2.05

**CNG, Gasoline and Diesel Price Increase.** Fuel price increase/inflation calculations based off the Energy Information Administration’s 2014 Early Release Annual Energy Outlook that estimates an annual percent increase from 2014 through 2040, and are as follows:

- Gasoline: 1.7 %
- Diesel: 2.2 %
- Natural Gas: -0.2 %

**Fuel Life Cycle Greenhouse Gas Factor.** This represents pounds of carbon dioxide (CO2) per gasoline gallon equivalent (GGE) emitted. For this model, we use a well to wheel philosophy, which takes into account the amount of CO2 expended to extract, refine/compress, transport, and consume gasoline, diesel and CNG to the appropriate infrastructure. We calculated the fuel life cycle GHG factor using the Argonne National Laboratory's Greenhouse Gasses, Regulated Emissions, and Energy Use in Transportation Model (GREET 2015), and is as follows:

- Gasoline: 25.4 pounds CO2/GGE
- Diesel: 25.4 pounds CO2/GGE
- CNG: 22.5 pounds CO2/GGE

**Excise Tax.** Both gasoline and diesel have a federal and state Excise tax. For the State Excise Tax we utilized a weighted average. Federal and State Excise tax is based on the American Petroleum Institute's State Motor Fuel Tax Report, and is as follows (American Petroleum Institute, 2016):

- Gasoline (Federal): $0.2746/gallon
- Gasoline (CA State): $0.2072/gallon
- Diesel (Federal): $0.3377
- Diesel (CA State) $0.2044

**Maintenance and Operating (M/O) Costs.** M/O costs for both diesel and CNG is $0.52 per mile. M/O costs for gasoline and CNG is $0.047. The reason for the decrease in price per mile is the fact that gasoline fuels vans and step vans that are significantly smaller than the diesel powered vehicles that we researched. Consequently, this leads to a significant decrease in M/O costs. This is based on research conducted by NREL and utilized in its VICE 2 model (Mitchell, 2015).

**Required Rate of Return/Nominal Discount Rate.** We used a Nominal Discount Rate of seven percent for our NPV calculations based on the Office of Management and Budget's (OMB) Circular A-94-Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs (Office of Management and Budget, 1992).

(v) Vehicle Acquisition Matrix

This section requires the number and type of vehicles to be purchased. There is a 20-year span that enables the user to spread out the purchase of an entire fleet.

(vi) Station Investment Matrix

This is the last section of the VICE 2 model and is only needed if infrastructure purchase is involved. The model will automatically updated this section if you choose project type 1 (vehicle and station) and investment type 1 (vehicle and station coupled). If you choose project type 1 and investment type 2, you would have to manually input the infrastructure costs.

## 2. Electric Vehicle Methodology

Within the last decade, we have seen a tremendous amount of growth in the EV market. As of 2017, we will see the introduction of the Tesla Model 3 and Chevrolet Bolt, which are light duty EVs. Each of these vehicles will be competitive in the LDV market with respect to cost and range. Although purchase costs remain high for EVs compared to conventional vehicles within the MDV/HDV markets, they still present many benefits that may counter the high purchase cost. As EDV technology matures, the anticipation is for purchase prices to decrease.

In order to compare diesel/gasoline and electric powered EVs from an investment standpoint we used a Net Present Value analysis. Cash flows were identified over time associated with the purchasing, fuel and maintenance costs. This allows us to compare the time-phased costs between electric and petroleum vehicles. This is a common practice for assisting businesses and organizations in making sound financial decisions. A description of our model architecture and available inputs follow.

A detailed financial analysis was performed, estimating and comparing the life cycle cost of our current internal combustion fleet versus that of an electrical fleet. The categories of costs taken into consideration are as follows: purchase costs, infrastructure costs, fuel/electricity costs and maintenance costs. These are described in the paragraphs below.

### *a. Purchase Costs*

Finding purchase costs for electric MDV/HDVs was one of the biggest obstacles encountered. For example, according to the National Geographic article “Tesla for the

Masses: Electric, fuel Cell Buses Take Off," a typical diesel bus costs $450,000 while electric buses of the same type costs approximately twice that (Koch, 2015). We found that data with regard to purchase costs was never explicit. For this reason, we decided to analyze the LDV market.

The LDV market was rich with purchase cost data for use. We collected and regressed the data on 13 LDVs in Table 18 based on weight and cost. When applying Regression Analysis to the data in Table 18 we found a correlation coefficient of 0.87.

Table 18. LDV Purchase Price Data. Adapted from U.S. Department of Energy (n.d.a).

| Brand | Weight | Cost |
|---|---|---|
| 2016 Smart fortwo | 2094 | $14,650 |
| 2016 Mitsubishi i-MiEV | 2579 | $22,995 |
| 2016 Chevrolet Spark | 2866 | $25,120 |
| 2016 Fiat 500e | 2980 | $31,800 |
| 2015 Kia Soul | 3289 | $15,190 |
| 2016 Nissan Leaf | 3391 | $29,010 |
| 2016 Volkswagen e-Golf | 3400 | $28,995 |
| 2016 Ford Focus | 3640 | $29,170 |
| 2016 Mercedes-Benz B250e | 3924 | $41,450 |
| 2016 Tesla Model S | 4608 | $70,000 |
| 2016 Tesla Model S AWD | 4936 | $75,000 |
| 2016 Tesla Model X AWD 90D | 5271 | $95,500 |
| 2016 Tesla Model X AWD P90D | 5381 | $115,500 |

Our next goal was to find a simple linear regression equation to calculate purchase cost. Through our analysis of the information from Table 18, we found our simple linear regression equation to be:

$$y = 28.94x - 61{,}934, \text{ where}$$

- $y$ = Cost in dollars
- $x$ = Weight of vehicle in pounds

Figure 50 shows the scatterplot of our data plus the simple linear regression model.

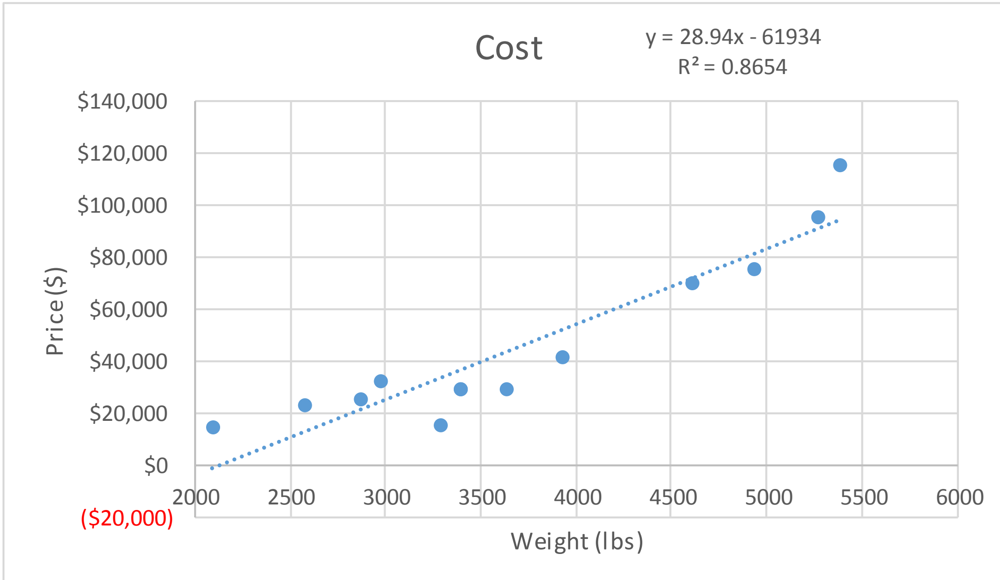



Figure 50. LDV Price ($) versus Weight (lbs)

We then looked at our MDV/HDV sample fleet, and found the most common type of vehicle, by quantity, within each of the five categories that we were analyzing (buses, tractor-trailers, fire trucks, step vans, and vans). Since we could not identify a market for electric fire trucks, we excluded them from this portion of our research. Table 19 shows all four types of vehicles with Gross Vehicle Weight Ratio (GVWR). The GVWR represents the independent variable in our simple linear and electric purchase cost equivalent represents the dependent variable.

Table 19. Electric Purchase Cost

| Type | Brand | Fleet Total | Brand Total | Gross Vehicle Weight Rating (GVWR) | Electric Purchase Cost Equivalent |
|---|---|---|---|---|---|
| Bus | Blue Bird | 69 | 50 | 36,200 lbs | $985,694.00 |
| Tractor Trailer | International Paystar (5000) | 62 | 20 | 58,000 lbs | $1,616,586.00 |
| Step Van | Utilimaster | 57 | 41 | 12,000 lbs | $285,346.00 |
| Van | Chevy Express (3500) | 52 | 25 | 9,600 lbs | $215,890.00 |

For an estimate of the petroleum to electric comparison with respect to purchase price, we utilized information provided to us from the Telematics Program Manager from

Southwest Region Fleet Transportation (SWRFT). This provided up-to-date purchase cost data for our sample fleet. Since there was no information with regard to buses in the report, we used a purchase price of $465,000 based on an average between purchase price stated in Koch's National Geographic article (stated $450,000.00) and Applied Economic Research Group's analysis of Florida's public buses (stated $480,000.00) (Atkins, McAlarney, & Wueen, 2013). The average purchase prices for petroleum buses, given by SWRFT, for tractor-trailers, step vans and vans are as follows:

- Buses - $465,000
- Tractor Trailers - $112,695
- Step Vans - $14,748
- Van - $70,935

(i) Infrastructure Costs

Infrastructure for EVs is known as electric vehicle supply equipment (EVSE) and is divided into three types of charging stations:

- AC Level 1 and AC Level 2, provide alternating current (AC) to the vehicle in which the vehicle's charging equipment converts to direct current (DC) to charge its batteries.
- The third type is known as a DC Fast Charging station, and provides DC directly to the cars battery (Smith & Castellano, 2015).

Data on these three charging stations are shown in Table 20, and distinguished by vehicle range added per charging time and power and supply power.

Table 20. Data on Electric Vehicle Charging Levels. Adapted from Smith & Castellano (2015).

| EVSE Type | Vehicle Range Added per Charging Time and Power | Supply Power |
|---|---|---|
| AC Level 1 | 4 mi/hr @ 1.4kW | 120 VAC/20 amps |
| | 6 mi/hr @ 1.9 kW | |
| AC Level 2 | 10 mi/hr @ 3.4 kW | 208/240 VAC/20-100 amps |
| | 20 mi/hr @ 6.6 kW | |
| | 60 mi/hr @ 19.2 kW | |
| DC Fast Charging | 24 mi/20 minutes @ 24 kW | 208/480 VAC 3-Phase |
| | 50 mi/20 minutes @ 50 kW | |
| | 90 mi/20 minutes @ 90 kW | |

EVSE infrastructure costs are considerably less than CNG based on a comparison of the information gathered in the CNG Case Study. Additionally, the EVSE are purchased on a per unit basis. This gives buyers more flexibility compared to CNG, gasoline and diesel because they are not required to dedicate a substantial amount of fixed upfront costs with regard to building a fueling station. Table 21 shows the EVSE unit cost range.

Table 21. ESVE Unit Cost Range. Adapted from Smith & Castellano (2015).

| EVSE Type | EVSE Unit Cost Range |
|---|---|
| AC Level 1 | \$300 - \$1,500 |
| AC Level 2 | \$400 - \$1,600 |
| DC Fast Charging | \$10,000 - \$40,000 |

The lower end of the unit cost range for all three EVSE types would be associated with the lower end of the vehicle range added per charging time and power found in Table 21. The same logic would be applied to the high-end EVSE unit cost range for all three EVSE types. The average unit cost for the three EVSE types:

- AC Level 1 - $900
- AC Level 2 - $1,000
- DC Fast Charging - $25,000 (Smith & Castellano, 2015).

We also estimated installation costs, which are driven by four primary factors: labor, materials, permits and taxes. Labor accounts for 55–60 percent of costs, materials for 30–35 percent, permits for 5 percent and taxes are 5 percent (Smith & Castellano, 2015). Table 22 shows the average installation cost per unit along with the installation cost range per unit.

Table 22. ESVE Installation Costs. Adapted from Smith & Castellano (2015).

| EVSE Type | Average Installation Cost (per unit) | Installation Cost Range (per unit) |
|---|---|---|
| AC Level 1 | Not Available | $0 - $3,000 |
| AC Level 2 | $3,000 | $600 - $12,700 |
| DC Fast Charging | $21,000 | $4,000 - $51,000 |

For our study, we computed an average installation cost for AC Level 1 and used the average installation cost in Table 22 for AC Level 2 and DC Fast Charging. We used the following average EVSE installation costs:

- AC Level 1 - $1,000
- AC Level 2 - $6,500
- DC Fast Charging - $30,000

We then combined the average costs for both units and installation for all three EVSE types:

- AC Level 1 - $1,900
- AC Level 2 - $7,500
- DC Fast Charging - $55,000

The last part of our analysis with respect to infrastructure costs was to determine how many and what type of units to purchase. Considering we did not include fire trucks in our analysis, that left us with 70 buses, 62 tractor trailers, 57 step vans and 52 vans for a total of 241 vehicles. Based on the information from Table 20, we concluded that one unit could service three vehicles, which equates to 80 units. As far as type of units we concluded that we would purchase seven DC Fast Charging stations (one for each base) to handle emergent situations. For the remainder of the units we accounted for 50 AC Level 2 and 23 AC Level 1. To calculate this cost we multiplied the combined (unit/installation) average cost. This cost is an initial cost and the breakdown is as follows:

- 7 DC Fast Charging * $55,000 = $385,000
- 50 AC Level 2 * $7,500 = $375,000
- 23 AC Level 1 * $1,900 = $43,700
- Total = $803,700

The combined unit and installation cost is the only cost used with respect to infrastructure. We did not take into account any rebates, tax incentives or infrastructure maintenance costs. Considering we are analyzing a DOD vehicle fleet, the rebates and tax incentives would not apply. As for maintenance cost with regard to infrastructure, cost information was not available, so we did not include it in our analysis. This is equivalent to assuming a value of zero for these costs.

#### *b. Fuel Costs*

Unlike CNG, there is a considerable price difference between electric and gasoline/diesel with respect to fuel costs. Just as in our CNG case study, we used the U.S. Department of Energy’s July 2016 alternative fuel price report and the comparison is as follows:

- Gasoline: $2.26 per gallon
- Diesel: $2.46 per gallon
- Electricity: $1.24 per GGE

Figure 51 shows the historical trends for these three fuels:

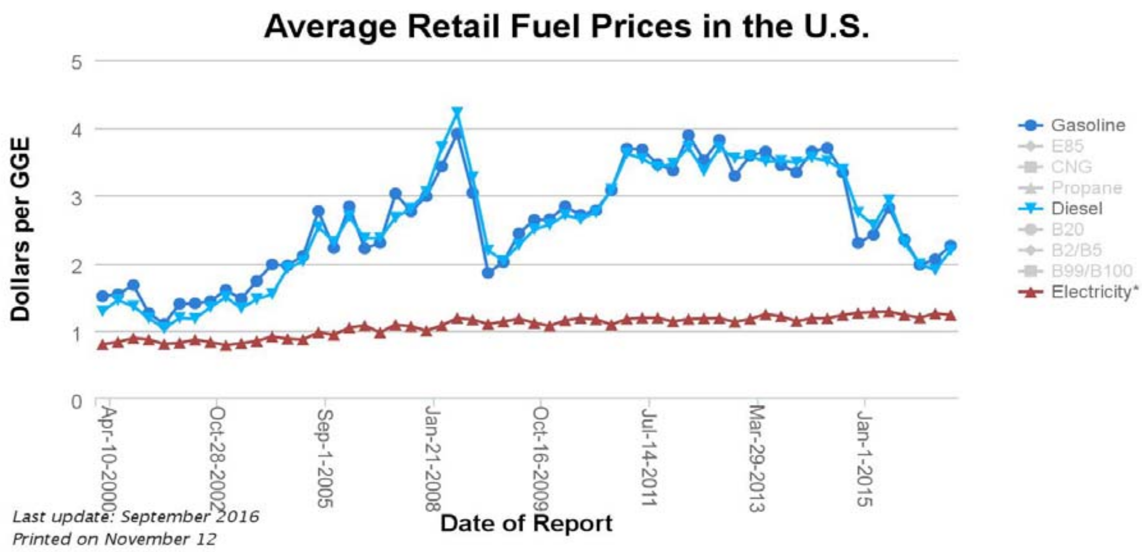



Figure 51. Average Retail Fuel Prices in the U.S.
Source: U.S. Department of Energy (2016).

We included efficiency as a factor. Based on results from the Altoona Bus Research and Testing Center, both Build Your Dreams (BYD) and Proterra electric bus manufactures yielded extreme increases in efficiency. BYD recorded 19 MPGe and Proterra recorded 22 MPGe. Compared to our fleet, which is similar, that represents a 288 percent and 333 percent increase in efficiency respectively. We used this information along with the same sample LDV market data used in Table 18 to calculate MPGe. Table 23 shows the sample LDV fleet in Table 18 along with given MPGe information.

Table 23. LDV Research (Weight–MPGe). Adapted from U.S. Department of Energy (n.d.a).

| Brand | Weight (lbs) | MPGe |
|---|---|---|
| 2016 Smart fortwo | 2094 | 108 |
| 2016 Mitsubishi i-MiEV | 2579 | 113 |
| 2016 Chevrolet Spark | 2866 | 118 |
| 2016 Fiat 500e | 2980 | 115 |
| 2016 BMW i3 | 3064 | 124 |
| 2015 Kia Soul | 3289 | 106 |
| 2016 Nissan Leaf | 3391 | 114 |
| 2016 Volkswagen e-Golf | 3400 | 116 |
| 2016 Chevrolet Volt | 3543 | 106 |
| 2016 Ford Focus | 3640 | 105 |
| 2016 Mercedes-Benz B250e | 3924 | 84 |
| 2016 Tesla Model S | 4608 | 89 |
| 2016 Tesla Model S AWD | 4936 | 92 |
| 2016 Tesla Model X AWD 90D | 5271 | 92 |
| 2016 Tesla Model X AWD P90D | 5381 | 89 |
| 2016 Proterra | 36000 | 22 |

If we were to regress this data using simple linear regression, we would calculate a negative MPGe for higher weight vehicles. For example, the simple linear equation for data in Table 23 is as follows:

$$y = -0.0099x + 140.88$$

in which:

$$y = \text{MPGe (dependent variable)}$$

$$x = \text{Weight (independent variable)}$$

If we were to use the simple linear equation to solve for the 2016 Proterra bus, we would find that MPGe equals -215.52.

Since a negative MPGe cannot exist, we used a logarithmic equation to regress the data. Regressing the data from Table 23, we got a much better fit, including a correlation coefficient of 0.88 and simple logarithmic equation of:

$$Y = -35.51 * \ln(x) + 394.94$$

A graph of our simple logarithmic equation is shown in Figure 52.

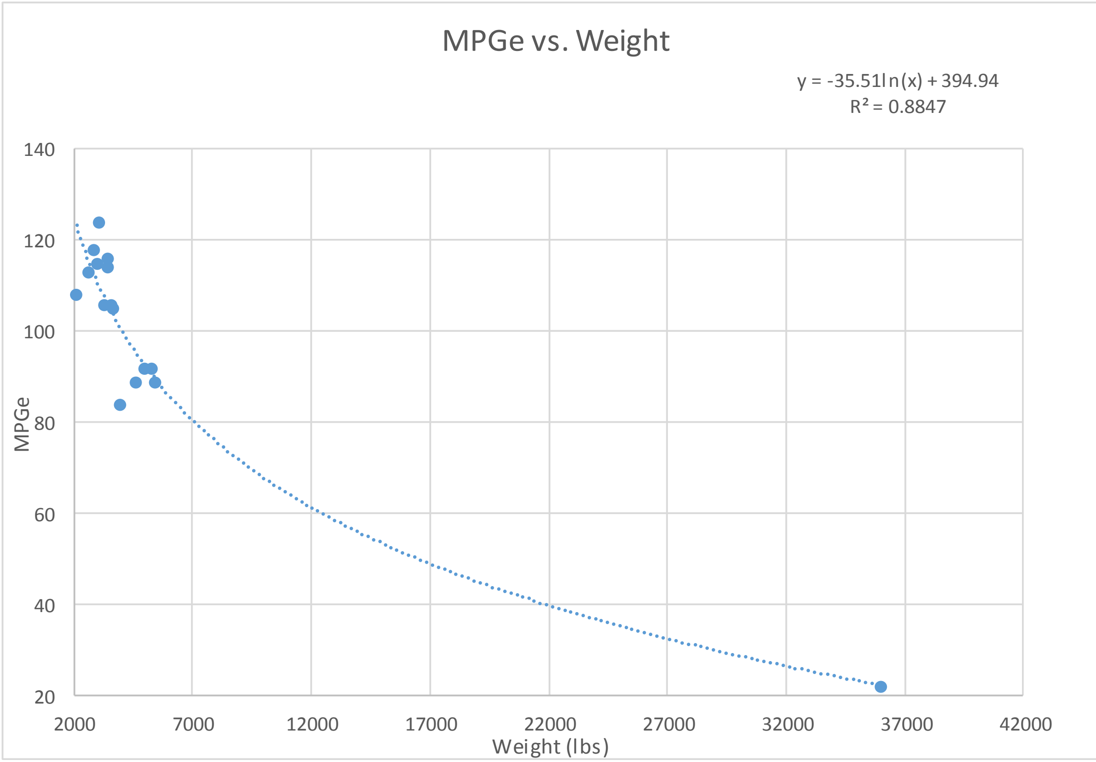



Figure 52. MPGe Simple Linear Graph

Using the same baseline for vehicle selection as we did in Table 19 we found an MPGe that could apply to our sample. Additionally, we took that efficiency and combined it with our fleet's average VMT and electric/petroleum fuel cost to compare the two. Table 24 shows this comparison.

Table 24. Electric–Petroleum Fuel Cost Comparison

| Type | Gross Vehicle Weight Rating | MPGe | VMT | Electric Annual Fuel Cost | MPG | Petroleum Annual Fuel Cost |
|---|---|---|---|---|---|---|
| Bus | 36,000 lbs | 22.4 | 16,311 | $902.93 | 6.6 | $6,079.55 |
| Tractor Trailer | 58,000 lbs | 8.7 | 20,601 | $2,936.23 | 6 | $8,446.41 |
| Step Van | 11,000 lbs | 64.5 | 7,533 | $144.82 | 9.33 | $1,824.71 |
| Van | 9,600 lbs | 69.3 | 7,884 | $141.07 | 8.03 | $2,218.91 |

Table 24 shows a big disparity in fuel costs due to the increased efficiency of electric and lower cost per GGE. Additionally, the VMT will play a large role because the more miles traveled the greater the savings on fuel costs. For example, we found that by using an electric bus we could save $5,176.62 annually on fuel costs. If VMT were to double from 16,311 miles to 32,622 miles, the annual fuel savings would increase to $10,353.24.

#### *c. Maintenance Costs*

The maintenance cost for gasoline/diesel MDV/HDVs include oil and filter changes, tire changes, brake pad replacements, large break/fix repairs and any other wear and tear items. Electric vehicles do not have the same complexities with regard to wear and tear as gasoline/diesel engines do. They do not require oil and filter changes and their brakes last significantly longer due to regenerative braking technology. The biggest maintenance worry for electric vehicles are their batteries and they usually come with a warranty. Tesla offers an eight-year, unlimited mileage warranty on their Model S (Healey, 2013). AER group's study, "An Impact Analysis of Electrifying Florida's Public Buses," concludes that there is a 50 percent increase in maintenance from electric to diesel. We have assumed a 40 percent increase from electric to diesel.

Table 25 shows a comparison of average annual maintenance cost for buses, tractor-trailers, step vans and vans based on information from the SWRFT FY 2016 Study and assumed electric maintenance cost.

Table 25. Annual Maintenance Cost Comparison

| Vehicle Type | Average Maintenance Cost (Gasoline/Diesel) | Average Maintenance Cost (Electric) |
|---|---|---|
| Bus | $4,000.00 | $2,857.00 |
| Tractor Trailer | $5,702.00 | $4,073.00 |
| Step Van | $1,892.00 | $1,351.00 |
| Van | $2,329.00 | $1,664.00 |

### 3. Hybrid-Electric Vehicle Methodology

Hybrid-Electric vehicles (HEV) have become relevant since the turn of the century because they produce less GHGs and are more efficient than vehicles powered strictly by internal combustion engines (ICE). HEVs are powered by an ICE, but also have an electric motor that uses energy that is stored in a battery. The electric motor helps power the vehicle, which in turn reduces the work required by the ICE. The additional power provided by the electric motor allows a smaller ICE to be used in a vehicle without surrendering performance. Additionally, the electric motor supports auxiliary loads such as audio systems and headlights while reducing engine idling when the vehicle is stopped. HEVs are not plugged in to recharge, but instead are charged by the ICE and regenerative braking.

In order to compare ICE and HEVs from an investment standpoint we used a NPV analysis. The relevant costs associated with each of the options such as purchasing and efficiency costs were identified. Maintenance cost were not included in our comparison because HEVs and ICEs have similar maintenance requirements due to savings gained with regenerative braking and minimal maintenance on the electrical system (U.S. Department of Energy, 2014). Additionally, we did not include any infrastructure costs because HEVs do not require any specialty infrastructure (e.g. CNG station, gas station, or EVSE). A description of our model architecture and available inputs follows.

A detailed financial analysis was performed, estimating and comparing the life cycle cost of our current internal combustion fleet versus that of a hybrid-electric fleet. The categories of costs taken into consideration are purchase and fuel costs. These are described in the paragraphs below.

### *a. Purchase Costs*

Finding purchase costs for hybrid-electric MDV/HDVs was an obstacle. Using the LDV market, we applied the same regression analysis approach to find an estimated HEV purchase price for our sample fleet as was done for electric vehicles. We collected and regressed the data on 12 hybrid-electric LDVs in Table 26 based on weight and cost. When applying regression analysis to the data in Table 26 we found a correlation coefficient of 0.70.

Table 26. Hybrid-Electric LDV Research (2016 Dollars). Adapted from U.S. Department of Energy (n.d.a).

| Brand | Weight | Cost |
|---|---|---|
| 2016 BMW ActiveHybrid 5 | 4365 | $62,100 |
| 2016 Toyota Highlander | 4861 | $47,870 |
| 2016 Acura RLX | 4312 | $59,950 |
| 2016 Subaru XV Crosstrek | 3451 | $26,395 |
| 2016 Lincoln MKZ | 3792 | $35,190 |
| 2016 Toyota Avalon | 3650 | $36,650 |
| 2016 Hyundai Sonata | 3497 | $26,000 |
| 2016 Toyota Camry | 3485 | $30,000 |
| 2016 Ford Fusion | 3615 | $25,675 |
| 2016 Volkswagon Jetta | 3411 | $31,120 |
| 2016 Chevrolet Malibu | 3457 | $21,625 |
| 2016 Toyota Prius | 3050 | $24,495 |

Through our analysis of the information from Table 26, we found our simple linear regression equation to be:

$$y = 22.587x - 49{,}012, \text{ where:}$$

- y = Cost in dollars
- x = Weight of vehicle in pounds

Figure 53 shows the scatterplot of our data plus the simple linear regression model.

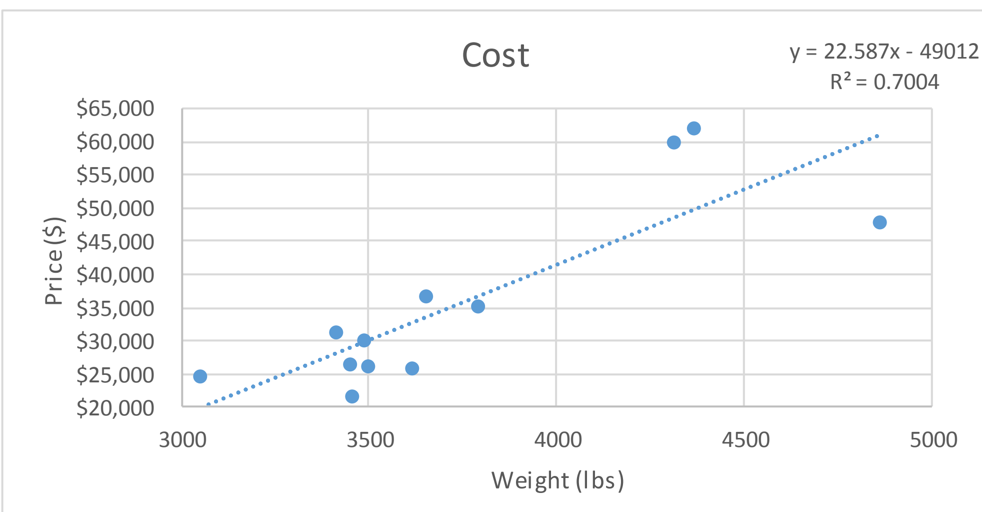


Figure 53. Hybrid-Electric Price ($) versus Weight (lbs)

We applied the same methodology as we did with our EV analysis, using the GVWR from Table 27 as our "x" variable. We excluded fire trucks from our hybrid-electric analysis because there is no market for hybrid-electric fire trucks. Table 27 shows the linear regression outputs for hybrid-electric purchase cost.

Table 27. HEV Purchase Cost

| Type | Brand | Fleet Total | Brand Total | GVWR | HEV Purchase Cost Equivalent |
|---|---|---|---|---|---|
| Bus | Blue Bird | 69 | 50 | 36,200 lbs | $768,637.40 |
| Tractor Trailer | International Paystar (5000) | 62 | 20 | 58,000 lbs | $1,261,034.00 |
| Step Van | Utilimaster | 57 | 41 | 12,000 lbs | $222,032.00 |
| Van | Chevy Express (3500) | 52 | 25 | 9,600 lbs | $167,823.20 |

The HEV purchase cost was an average of 22 percent less, per vehicle type, than the EV purchase cost equivalent calculated in our EV case study. Table 28 shows the comparison between the purchase costs for our electric and hybrid electric sample fleet.

Table 28. Electric Vehicle versus Hybrid-Electric Cost Comparison

| Type | Electric Purchase Cost | Hybid Purchase Cost |
|---|---|---|
| Bus | $985,694.00 | $768,637.00 |
| Tractor Trailer | $1,616,586.00 | $1,261,034.00 |
| Step Van | $285,346.00 | $222,032.00 |
| Van | $215,890.00 | $167,823.00 |

To compare vehicle purchase cost with our current petroleum sample fleet, not including buses, we utilized the SWRFT study. For buses, we used the same average ($465,000) as we did in our EV case study. The purchase costs for our petroleum sample fleet is as follows:

- Buses - $465,000
- Tractor Trailers - $112,695

- Step Vans - $14,748
- Van - $70,935

### *b. Fuel Efficiency Costs*

Utilizing Hybrid vehicles meant that we did not have to consider fuel price differences because the hybrid-electric vehicles we are analyzing use a gas/diesel ICE. Additionally, the ICE charges the hybrid vehicle's battery so there is no charge for electricity. Considering this, efficiency (dollars per MPGe), would be the only thing we would factor with regard to fuel costs. However, this proved difficult because our regression analysis did not provide applicable data. For example, we found the weight and MPGe of the same 12 LDVs that we did to calculate purchase cost for vehicles in Table 26. This weight and MPGe for these vehicles are shown in Table 29.

Table 29. Hybrid-Electric LDV Weight versus MPGe Comparison. Adapted from U.S. Department of Energy (n.d.a).

| Brand | Weight | MPGe |
|---|---|---|
| 2016 BMW ActiveHybrid 5 | 4365 | 27 |
| 2016 Toyota Highlander | 4861 | 28 |
| 2016 Acura RLX | 4312 | 30 |
| 2016 Subaru XV Crosstrek | 3451 | 32 |
| 2016 Lincoln MKZ | 3792 | 40 |
| 2016 Toyota Avalon | 3650 | 40 |
| 2016 Hyundai Sonata | 3497 | 41 |
| 2016 Toyota Camry | 3485 | 41 |
| 2016 Ford Fusion | 3615 | 43 |
| 2016 Volkswagon Jetta | 3411 | 45 |
| 2016 Chevrolet Malibu | 3457 | 47 |
| 2016 Toyota Prius | 3050 | 52 |

From Table 29, we regressed the weight against MPGe of the 12 LDVs. This enabled us to formulate both a simple linear equation and logarithmic equation to calculate MPGe in our sample fleet. Through our analysis, we found a correlation coefficient of .72 for our simple linear regression and .75 for our logarithmic regression. Our simple linear and logarithmic regression equations are as follows:

$$y = -0.0133x + 88.499$$

$$y = -52.92\ln(x) + 473.67, \text{ where}$$

- y = MPGe
- x = Weight of vehicle in pounds

When we used a GVWR of 36,200 lbs, which represents the Blue Bird bus in Table 27, as the independent variable (x), we computed the following results:

- Linear - $y=-0.0133(36{,}200)+88.499=$ -392.96
- Logarithmic - $y=-52.921\ln(36{,}200)+473.67=$ -81.83

Although it is reasonable to suggest that the more a vehicle weighs the greater the reduction in MPGe, we could not use a negative MPGe to calculate fuel costs for hybrid-electric MDV/HDVs. We decided to use market data to estimate hybrid-electric fuel costs. The following represents efficiency percent increases over similar petroleum powered vehicles.

- Bus – 18% (Walkowicz, 2006).
- Tractor-Trailer – 12% (Walkowicz, Lammert, & Curran, 2012).
- Step Vans – 12% (Walkowicz, & Lammert, 2012).
- Vans – 25% (Green Fleet, 2016).

Table 30 shows the MPG comparison between the known MPG data of our sample fleet and HEV MPGe based on market data. To calculate the HEV MPG, we multiplied the increased efficiency that we researched by the known average gas/diesel MPG of our sample fleet. For example, a diesel bus in our sample fleet averages 6.6 MPG. If we multiply that by the increased efficiency (6.6 * 1.18), we get an average HEV MPG of 7.79.

Table 30. Hybrid-Electric MPGe Comparison

| Vehicle Classification | Average Gas/Diesel MPG | Average HEV MPG |
|---|---|---|
| Bus | 6.6 | 7.79 |
| Tractor Trailer | 6 | 6.72 |
| Step Van | 9.33 | 10.45 |
| Van | 8.03 | 10.04 |

Using the data from Table 30, we calculated an annual fuel cost comparison between our sample fleet and a sample HEV fleet of the same construct. For example, a tractor-trailer's efficiency increases from 6 MPG to 6.72 MPG by switching from diesel to hybrid-electric. This translates into a reduction of annual fuel costs from $8,446.41 to $7,541.44. Table 31 shows this comparison.

Table 31. Hybrid-Electric Vehicle–Petroleum Annual Fuel Cost Comparison

| Type | Gross Vehicle Weight Rating | MPGe | VMT | Hybrid Annual Fuel Cost | MPG | Petroleum Annual Fuel Cost |
|---|---|---|---|---|---|---|
| Bus | 36,000 lbs | 7.79 | 16,311 | $5,150.84 | 6.6 | $6,079.55 |
| Tractor Trailer | 58,000 lbs | 6.72 | 20,601 | $7,541.44 | 6 | $8,446.41 |
| Step Van | 11,000 lbs | 10.45 | 7,533 | $1,629.15 | 9.33 | $1,824.71 |
| Van | 9,600 lbs | 10.04 | 7,884 | $1,774.69 | 8.03 | $2,218.91 |

Although this does not show the same disparity in fuel costs as our EV comparison, it does show that HEVs are more efficient and saves on annual fuel costs. For example, if the tractor-trailer we examined above were electric, its annual fuel cost would reduce to $2,936.23. Table 32 shows the annual fuel cost comparisons of petroleum, hybrid and electric.

Table 32. Petroleum, Hybrid and Electric Annual Fuel Cost Comparison

| Type | Petroleum Annual Fuel Cost | Hybrid Annual Fuel Cost | Electric Annual Fuel Cost |
|---|---|---|---|
| Bus | $6,079.55 | $5,150.84 | $902.93 |
| Tractor Trailer | $8,446.41 | $7,541.44 | $2,936.23 |
| Step Van | $1,824.71 | $1,629.15 | $144.82 |
| Van | $2,218.91 | $1,774.69 | $141.07 |

Additionally, as in our EV case study, VMT can play a role in cost savings. For example, we found that by using a hybrid-electric bus we could save $928.71 annually on fuel costs. If VMT were to double from 16,311 miles to 32,622 miles, the annual fuel savings would also double.

## B. APPLICATIONS

### 1. Case Study CNG

Table 33 displays the telematics gathered from our sample fleet and includes Vehicle Classification, Quantity, Average MPG and VMT. The average MPG for Fire Trucks and Tractor Trailers were not available via telematics, so we used data from the Center of Transportation Analysis' 2015 Vehicle Technologies Market Report (Oak Ridge National Laboratory, 2015).

Table 33. Vehicle Class, Quantity, Average MPG, & Average VMT for CNG Case Study. Source: Mortlock, Whittaker, & Roberts (2016).

| Vehicle Classification | Quantity | Average MPG | Average Vehicle Miles Traveled (VMT) |
|---|---|---|---|
| Buses | 70 | 6.6 | 16,311 |
| Fire Trucks | 106 | 6 | 4,067 |
| Tractor Trailers | 62 | 6 | 20,601 |
| Step Vans | 57 | 9.33 | 7,533 |
| Vans | 52 | 8.03 | 7,884 |

#### *a. Case Study Methodology*

Since we were unable to identify a significant market for CNG Step Vans and Vans, we eliminated them from our case study and limited our focus to buses, fire trucks and tractor-trailers. We utilized the VICE 2 model to assess the financial soundness of converting our sample fleet to run on CNG. An assumption that we made was that since fleets are not replaced over a one-year period, we evenly dispersed the replacement of our sample fleet over a 10-year period. For example, there are 70 total buses in our sample according to Table 33, so they are replaced at a rate of seven buses per year over a 10-year period.

Our first NPV iteration through the VICE 2 model would include the entire fleet of Buses, fire trucks and tractor-trailers while having a "Vehicle only" project type. We did not include infrastructure, as that will be addressed in a later section.

(i) Vehicle Only Project Type

The first run through the VICE 2 model with the information in Table 33, coupled with the parameters set forth in our CNG methodology section provided the following results:

- Net Present Value: ($5,191,668)
- Payback Period (years): > 15
- Total Incremental Cost: $10,075,810
- Displaced Diesel (GGEs): 7,573,170
- Project Lifetime GHG Displacement (tons): 81,211

Although the displaced diesel GGEs and project lifetime GHG displaced is positive, the NPV, payback period and total incremental cost show that this is not a good investment. There is one primary reason for this and that is centered on the differentiation between diesel price per gallon and CNG price per GGE.

(ii) Diesel-CNG Breakeven Analysis

The difference between diesel price per gallon and CNG price per GGE plays a significant role with respect to NPV, payback period and total incremental cost. The prices we use were based on the July 2016 alternative fuel price report and has a diesel-CNG differential of $0.41 (Diesel costs–$2.46, CNG costs–$2.05). Figure 54 shows a breakeven analysis with respect to diesel price per gallon and CNG price per GGE in which NPV is greater than zero. For example, if CNG costs $2.00 per GGE for our “total” fleet sample (annotated in blue in Figure 54) then diesel would need to cost $3.55 per gallon to make this case economically viable.

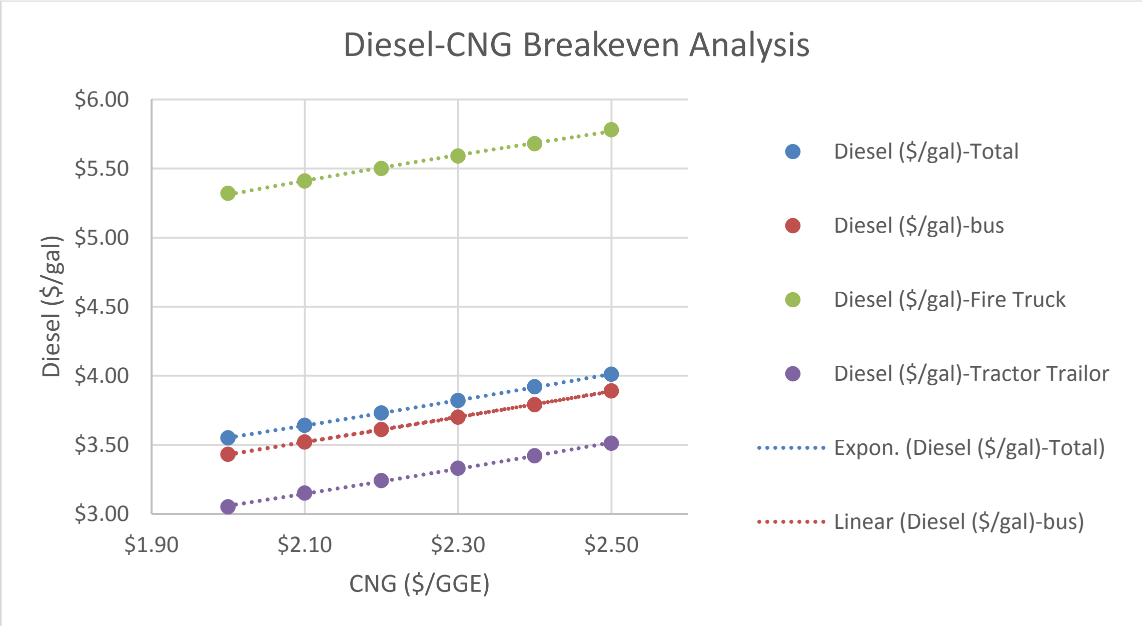



Figure 54. Diesel—CNG Breakeven Analysis.

As the figure shows, the total breakeven point is slightly higher than the breakeven points of both buses and tractor-trailers yet significantly lower than the breakeven point for fire trucks. Table 34 shows the details of the above analysis.

Table 34. Diesel—CNG Breakeven Numerical Analysis.

| CNG ($/GGE) | Diesel ($/gal)-Total | Diesel ($/gal)-bus | Diesel ($/gal)-Fire Truck | Diesel ($/gal)-Tractor Trailor |
|---|---|---|---|---|
| $2.00 | $3.55 | $3.43 | $5.32 | $3.05 |
| $2.10 | $3.64 | $3.52 | $5.41 | $3.15 |
| $2.20 | $3.73 | $3.61 | $5.50 | $3.24 |
| $2.30 | $3.82 | $3.70 | $5.59 | $3.33 |
| $2.40 | $3.92 | $3.79 | $5.68 | $3.42 |
| $2.50 | $4.01 | $3.89 | $5.78 | $3.51 |

(iii) Fuel Price Differentiation

Another way we differentiated between diesel price per gallon and CNG price per GGE was to examine the payback period of CNG with a fixed fuel price difference. Figure 55 shows the effect that cost differential can have on the simple payback period of our CNG analysis. We used $2.05 per GGE as our CNG baseline.

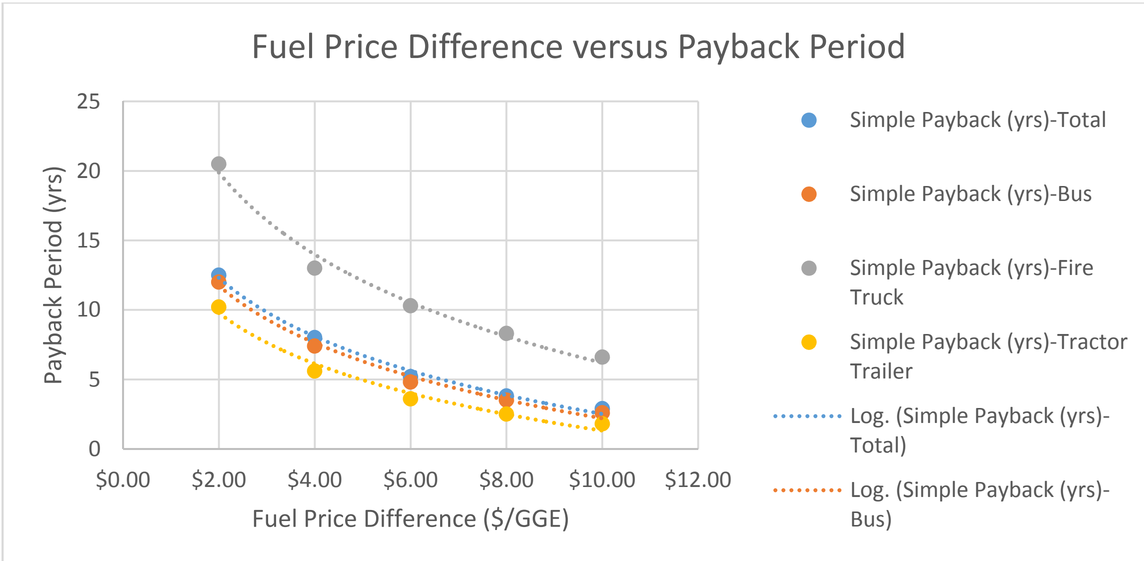



Figure 55. Diesel—CNG Fuel Price Difference versus Simple Payback.

The results of Figure 55 show a similarity to Figure 54 in that they are sensitive to the price difference with regard to diesel and CNG. Additionally, the simple payback for buses and tractor-trailers are significantly lower than fire trucks. The reason for this is the VMT shown in Table 33. The less the VMT, the less benefit we received from the diesel-CNG cost differentiation. This is why Fire Trucks have a significantly higher payback period (Figure 54) and breakeven point (Table 34) when compared to buses and tractor-trailers.

(iv) VMT

Figure 56, taken from the Federal Highway Administration shows the average annual miles traveled (per vehicle) by major vehicle categories in the United States (Federal Highway Administration, 2015). Comparing this data with the data in Table 33, we see that the VMT for transit buses is 16,311. Figure 56 shows that transit buses throughout the U.S. have an average VMT of 34,053. Additionally, the comparison between class 8 trucks (tractor-trailers) and Tractor Trailers from our sample show a high disparity of 68,155 VMT (Figure 56) to 20,601 VMT (Table 33). Fire Truck data was insufficient so for the VMT analysis we did not change VMT from Table 33. Although are sample size of vehicles are utilized differently than the average vehicles depicted in

Figure 56, the high disparity might indicate an opportunity to better utilize our vehicles. For the VMT analysis, we assumed that if we could increase VMT by 20 percent then we could decrease quantity by 20 percent. This is important to show the impact that utilization can have on NPV and breakeven analysis and is illustrated in Table 35.

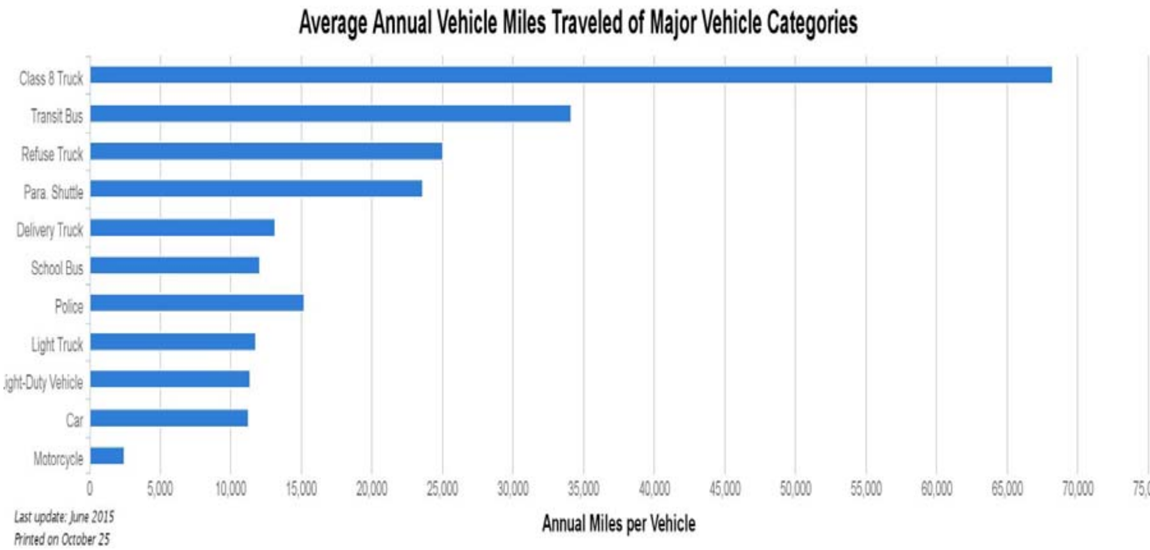



Figure 56. VMT by Major Vehicle Categories. Source: Federal Highway Administration (2015).

Table 35. Twenty Percent Reduction in Quantity, 20 Percent Increase in VMT for CNG Case Study.

| Vehicle Classification | Quantity | Average Yearly Miles |
|---|---|---|
| Buses | 60 | 19,573 |
| Fire Trucks | 106 | 4,067 |
| Tractor Trailers | 50 | 24,721 |

Applying the data in Table 35 into the VICE 2 model, as we had done with the data in Table 33 provided the following results:

- Net Present Value: ($4,314,609)
- Payback Period (years): > 15
- Total Incremental Cost: $8,926,390

- Displaced Diesel (GGEs): 7,516,563
- Project Lifetime GHG Displacement (tons): 80,615

This represents a 17 percent increase in NPV, 11 percent decrease in total incremental cost and a one percent increase for both the displaced diesel (GGEs) and project lifetime GHG displaced (tons). These numbers denote a comparison in NPV, payback period, total incremental cost, displaced diesel and project lifetime GHG displaced between Tables 7 and 35 in which we showed the effect of reducing VMT within our sample. Although payback period remained greater than the project's life, we noticed positive trends with NPV and total incremental cost with a minimal change to diesel displacement.

Figure 57 shows the breakeven analysis with the information in Table 35 compared to the "Total" breakeven analysis shown in Figure 54.

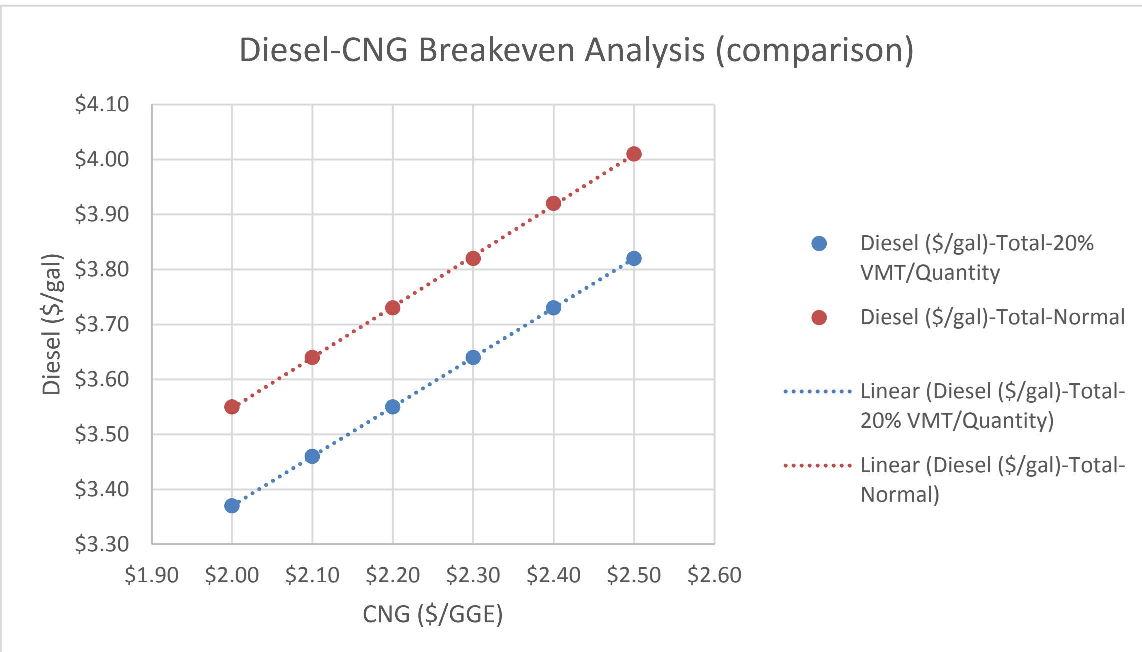



Figure 57. Diesel—CNG Breakeven Analysis (Comparison).

The average difference in diesel cost per gallon with regard to Figure 57 is $0.1834. This shows that if we utilize our fleets 20 percent more efficiently we can reduce the diesel-CNG breakeven point. For example, Table 34 shows the diesel-CNG breakeven point to be $3.55 per gallon of diesel when CNG costs $2.00 per GGE. If we were to apply a 20 percent increase in VMT, we could lower the diesel-CNG breakeven point to $3.37 per gallon of diesel when CNG remains at $2.00 per GGE.

Although fuel price comparisons coupled with utilization rates are important aspects to building a CNG business case the fact remains that the infrastructure needed to service CNG vehicles is a big underlying cost.

(v) Vehicle and Station Project Type

Investment profitability, measured by either NPV or payback periods, is dependent on initial upfront costs (so-called CAPEX), as well as downstream operating costs (so-called OPEX). Our sample included vehicles from seven separate Marine Corps bases and of those seven, three had CNG infrastructure in place. Consequently, over half the bases we considered will have a substantial upfront cost to contend with.

Just as we did with “Vehicle only Project Type” we applied data from Table 33 within the parameters laid out in our CNG methodology section into the VICE 2 model. With this iteration however, we changed “Project Type” to “1=Vehicle & Station” and “Investment Type” to “1=Vehicle and Station coupled.” This sets our model up to automatically apply infrastructure costs to our results. The VICE 2 model presented the following initial data:

- Net Present Value: ($10,246,167)
- Payback Period (years): > 15
- Total Incremental Cost: $10,075,810
- Displaced Diesel (GGEs): 7,572,170
- Project Lifetime GHG Displacement (tons): 81,211

By taking into account infrastructure, NPV decreased from ($5,191,668) to (10,246,167). Payback period was still greater than the project life of 15 yrs. Total incremental cost, displaced diesel (GGEs) and project lifetime GHG displaced (tons) were not affected.

(vi) Diesel – CNG Breakeven Analysis (Infrastructure Costs)

Figure 58 shows the Diesel-CNG breakeven analysis when taking into account infrastructure costs.

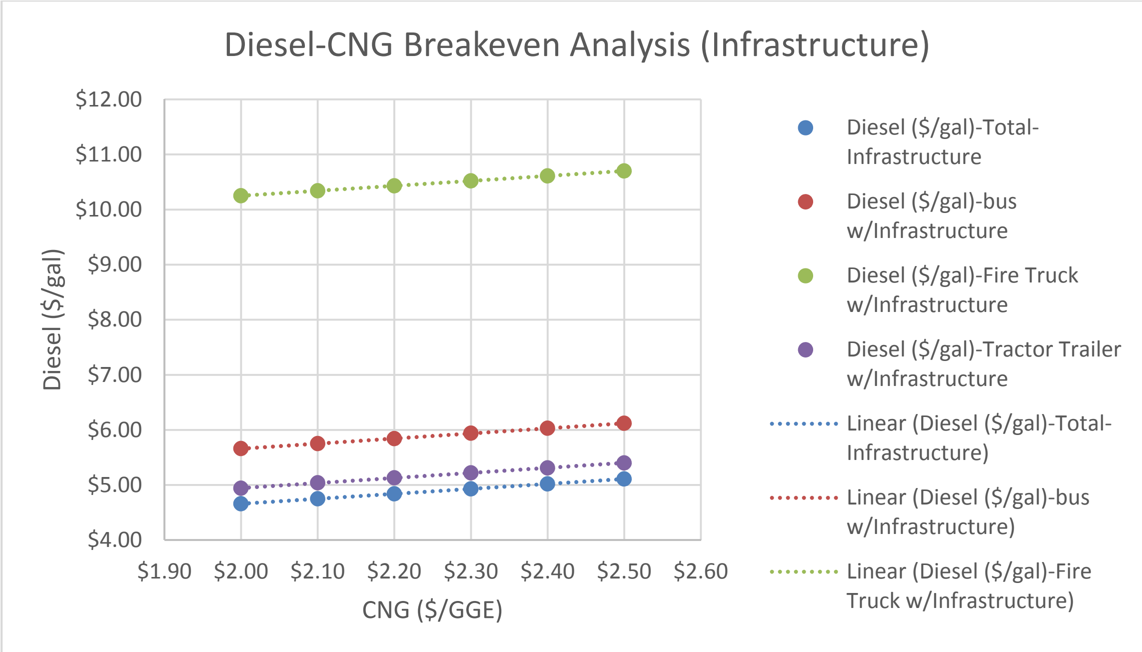



Figure 58. Diesel—CNG Breakeven Analysis (Infrastructure Costs)

When comparing the breakeven analysis of diesel price per gallon with respect to infrastructure and non-infrastructure projects we found an average of $1.11 per gallon would be added due to infrastructure. Additionally, the trend line for the "Total" diesel price per gallon is below that of all individually looked at vehicles. This is significantly different than our first breakeven analysis (Figure 54) because of the effect fleet size has on infrastructure. The numerical analysis is shown in Table 36.

Table 36. Diesel—CNG Breakeven Numerical Analysis (Infrastructure Costs).

| CNG ($/GGE) | Diesel ($/gal)-Total-Infrastructure | Diesel ($/gal)-bus w/Infrastructure | Diesel ($/gal)-Fire Truck w/Infrastructure | Diesel ($/gal)-Tractor Trailer w/Infrastructure |
|---|---|---|---|---|
| $2.00 | $4.66 | $5.66 | $10.25 | $4.94 |
| $2.10 | $4.75 | $5.75 | $10.34 | $5.04 |
| $2.20 | $4.84 | $5.84 | $10.43 | $5.13 |
| $2.30 | $4.93 | $5.94 | $10.52 | $5.22 |
| $2.40 | $5.02 | $6.03 | $10.61 | $5.31 |
| $2.50 | $5.11 | $6.12 | $10.70 | $5.40 |

(vii) Simple Payback versus Fleet Size

Another aspect we wanted to consider was the effect the size of the fleet had on a simple payback period. The reason why we found this to be important because it shows that infrastructure is a fixed cost therefore the bigger the CNG vehicle fleet the lesser the effect that infrastructure had on payback periods. This case only works if there is a breakeven point between CNG ($/GGE) and diesel ($/gal) therefore we assumed a breakeven point that aligned with CNG ($/GGE) = $2.00 and diesel ($/gal). Figure 59 shows the simple payback vs. fleet size.

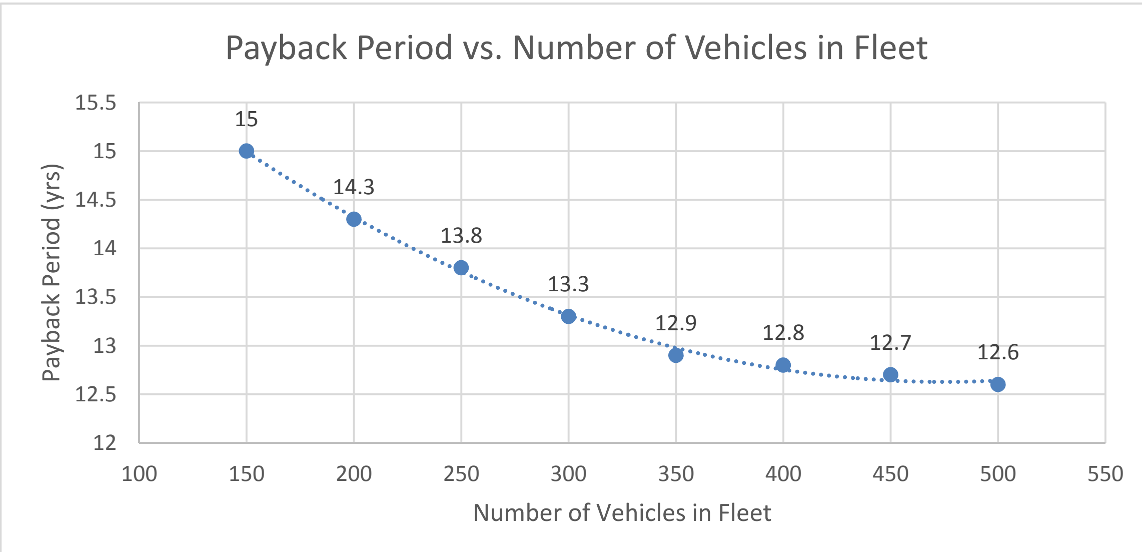



Figure 59. Simple Payback versus Number of Vehicles in Fleet

Figure 59 follows a logarithmic pattern and indicates that a larger number of vehicles in a fleet reduces the effect of a simple payback period with regard to infrastructure.

#### *b. Conclusion*

The financial attractiveness of an investment project is important when making coherent financial decisions. While there are many variables of a CNG vehicle and infrastructure project that must be taken into account to successfully define overall profitability, NREL has developed the VICE 2 model to help organizations evaluate the financial reliability with regard to CNG vehicle and infrastructure investments. The model accomplishes this by determining NPV, total incremental cost, payback periods and GHG savings.

The most important factors with regard to our analysis is fuel and infrastructure costs. VMT indicate strong effects as well. The diesel fuel replaced with CNG and the larger the price differential, the better the investment. If a fleet has a lower average VMT, which is indicative of lower fuel consumption, the less desirable the investment becomes.

Infrastructure costs has an impact from the standpoint of number of vehicles within a fleet. The greater the number of vehicles in a fleet the less of a factor infrastructure costs become. With our study, we were able to show that if a fleet size increased by 70 percent, the payback period can be reduced by 16 percent when taking into account infrastructure costs. Although this reduction might not seem significant, it may mean the difference between a go and no-go decision.

### 2. Case Study Electric

We started our NPV model by comparing vehicles on an individual basis. Tables 37–40 show the NPV comparison for buses, tractor-trailers, step vans and vans. We used the same discount rate and years of service as our CNG case study. CO2 produced data was calculated through the Argonne National Laboratory's GREET model. We calculated the CO2 produced using a well-to-wheel (WTW) analysis that examines energy use and emissions from primary energy source through the operation of a vehicle.

Table 37. Bus NPV Comparison

| | | | | |
|---|---|---|---|---|
| **Discount Rate** | 7% | | | |
| | | | | |
| **Type of Vehicle** | | Bus (Diesel) | | Bus (electric) |
| **Purchase Cost** | | $465,000.00 | | $985,694.00 |
| **Infrastructure Cost** | | $0.00 | | $7,500.00 |
| **Miles/yr (VMT)** | | 16,311 | | 16,311 |
| **Years of Service** | | 15 | | 15 |
| **Fuel Cost/yr** | | $6,079.55 | | $902.93 |
| **Maintenance/yr** | | $4,000.00 | | $2,857.00 |
| **CO2 produced (kg/mi)** | | 2.95 | | 1.41 |
| | | | | |
| **NPV** | | ($499,141.57) | | ($1,005,929.60) |
| **Per Mile** | | ($2.04) | | ($4.11) |

Table 38. Tractor-Trailer NPV Comparison

| | | | | |
|---|---|---|---|---|
| **Discount Rate** | 7% | | | |
| | | | | |
| **Type of Vehicle** | | Tractor Trailer (diesel | | Tractor Trailer (electric) |
| **Purchase Cost** | | $112,695.00 | | $1,616,586.00 |
| **Infrastructure Cost** | | $0.00 | | $7,500.00 |
| **Miles/yr (VMT)** | | 20,601 | | 20,601 |
| **Years of Service** | | 15 | | 15 |
| **Fuel Cost/yr** | | $8,446.41 | | $2,936.23 |
| **Maintenance/yr** | | $5,702.00 | | $4,073.00 |
| **CO2 produced (kg/mi)** | | 2.12 | | 1.08 |
| | | | | |
| **NPV** | | ($160,618.65) | | ($1,647,827.74) |
| **Per Mile** | | ($0.52) | | ($7.49) |

Table 39. Step Van NPV Comparison

| | | | | |
|---|---|---|---|---|
| **Discount Rate** | 7% | | | |
| | | | | |
| **Type of Vehicle** | | Step Van (gasoline) | | Step Van (electric) |
| **Purchase Cost** | | $14,748.00 | | $285,346.00 |
| **Infrastructure Cost** | | $0.00 | | $7,500.00 |
| **Miles/yr (VMT)** | | 7,533 | | 7,533 |
| **Years of Service** | | 15 | | 15 |
| **Fuel Cost/yr** | | $1,824.71 | | $144.82 |
| **Maintenance/yr** | | $1,892.00 | | $1,351.00 |
| **CO2 produced (kg/mi)** | | 0.99 | | 0.16 |
| | | | | |
| **NPV** | | ($27,337.28) | | ($297,912.66) |
| **Per Mile** | | ($0.24) | | ($2.64) |

Table 40. Van NPV Comparison

| | | | | |
|---|---|---|---|---|
| **Discount Rate** | 7% | | | |
| | | | | |
| **Type of Vehicle** | | Van (gasoline) | | Van (electric) |
| **Purchase Cost** | | $70,935.00 | | $215,890.00 |
| **Miles/yr (VMT)** | | 7,884 | | 7,884 |
| **Years of Service** | | 15 | | 15 |
| **Fuel Cost/yr** | | $2,218.91 | | $144.82 |
| **Maintenance/yr** | | $2,329.00 | | $1,664.00 |
| **CO2 produced (kg/mi)** | | 2.95 | | 1.41 |
| | | | | |
| **NPV** | | ($86,339.73) | | ($229,516.86) |
| **Per Mile** | | ($0.60) | | ($1.94) |

Although the $CO_2$ produced, maintenance costs, and fuel costs are lower for electric vehicles; the significant NPV differences show that none of these vehicles is a good financial investment. Additionally, because of the negative NPV, the Payback Period would be greater than years of service. The primary reason for this is the large disparity in purchase cost.

#### *a. Purchase Cost Breakeven Analysis*

Going into our analysis, we suspected the purchase cost was going to be the biggest barrier to overcome when comparing petroleum to electric for electric to be cost competitive. We did not suspect that it would be as drastic as our analysis states. Figure 60 shows a purchase cost breakeven analysis for buses in which the NPV for electric buses equals that of diesel buses. For example, if a diesel powered bus cost $450,000.00 to purchase, an electric bus would need to cost $471,400.00 to be financially competitive.

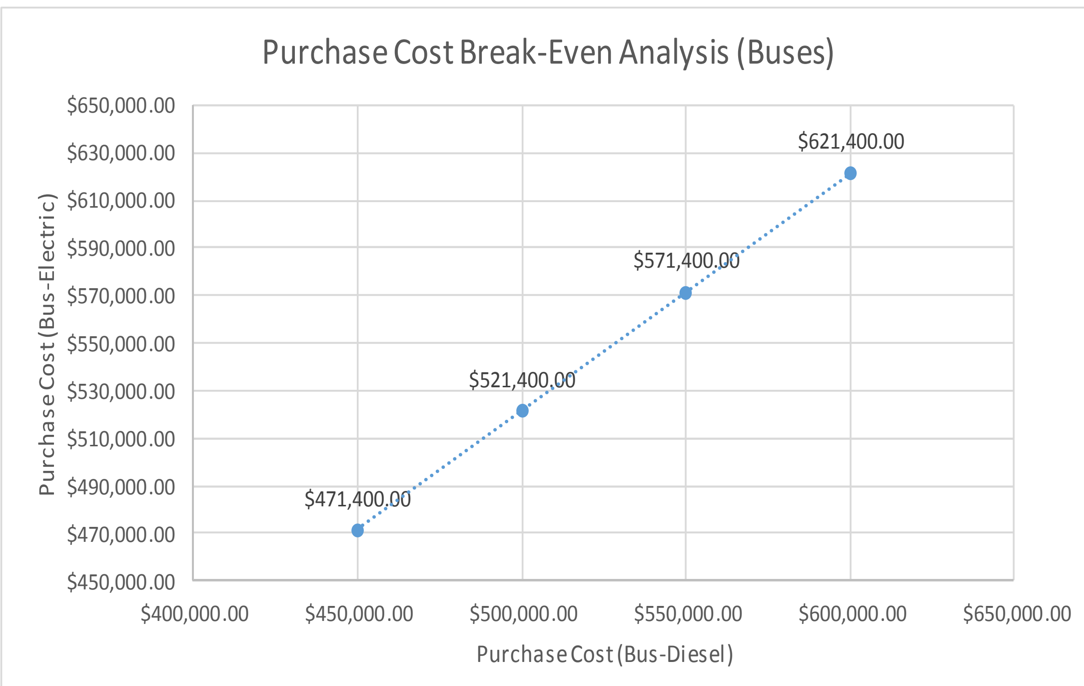



Figure 60. Purchase Cost Breakeven Analysis (Buses)

Another area that is an opportunity for electric to become more viable was to better utilize these vehicles. This is the same approach we took with our CNG analysis.

CNG, however, does not provide as much of a difference in fuel cost (CNG - $2.05/GGE) as electric does ($1.24/GGE) when compared to diesel ($2.46/gal). Figure 61 shows the same bus break-even analysis shown in Figure 60; however, we increased VMT from 16,311 miles per year to the Federal transit bus average VMT of 34,053 miles per year. (Federal Highway Administration, 2015).

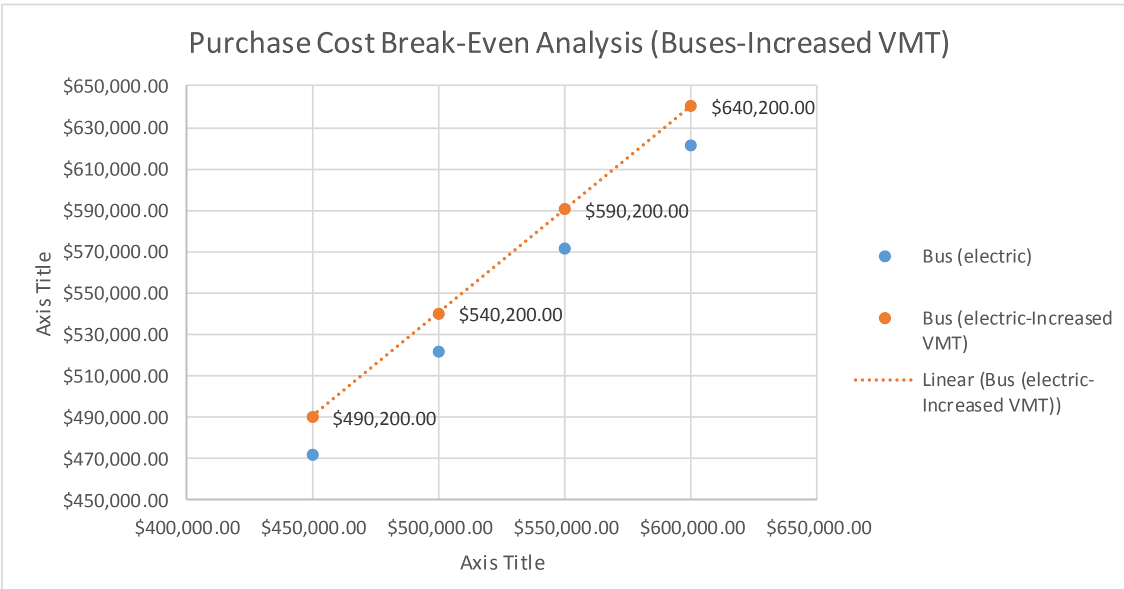



Figure 61. Purchase Cost Breakeven Analysis (Buses–Increased VMT)

Before we increased the VMT, we showed that if a diesel powered bus cost $450,000.00 to purchase; an electric bus would need to cost $471,400.00 to be financially competitive. By increasing the VMT to the Federal average, we were able to raise the breakeven cost from $471,400.00 to $490,200.00. What this means is that by increasing the VMT, we were able to increase the money in which we could purchase an electric bus and still breakeven. The breakeven analysis for all vehicles are located in Table 41.

Table 41. Breakeven Purchase Price (All Vehicles)

| | Diesel-Purchase Cost | | Electric-Break Even |
|---|---|---|---|
| **Bus** | $450,000.00 | | $471,400.00 |
| | $500,000.00 | | $521,400.00 |
| | $550,000.00 | | $571,400.00 |
| | $600,000.00 | | $621,400.00 |
| | | | |
| **Tractor Trailer** | $100,000.00 | | $124,100.00 |
| | $150,000.00 | | $174,100.00 |
| | $200,000.00 | | $224,000.00 |
| | $250,000.00 | | $274,000.00 |
| | | | |
| **Step Van** | $15,000.00 | | $22,500.00 |
| | $25,000.00 | | $32,500.00 |
| | $35,000.00 | | $42,500.00 |
| | $45,000.00 | | $52,500.00 |
| | | | |
| **Van** | $60,000.00 | | $69,200.00 |
| | $70,000.00 | | $79,200.00 |
| | $80,000.00 | | $89,200.00 |
| | $90,000.00 | | $99,200.00 |

### *b. Conclusion*

Electric vehicles are the least environmentally impactful vehicles with respect to our study, but are also the least financially sound. We showed that EVs are more efficient, cost less with respect to fuel, and have less maintenance cost. The high purchase costs, however, outweigh all of the incentives that electric brings to the MDV/HDV market. For example, for a battery (electric) powered tractor-trailer to be competitive with a diesel-powered tractor-trailer, its purchase price would have to decrease by 90.3 percent. Although the high purchase price might deem electric MDV/HDV as a bad investment, there is hope for the future.

Electric has really expanded in the LDV market within the last five years. A big reason for this is that manufacturers stopped relying just on the fact that EVs produce zero GHG emissions and started making it cost competitive. It remains to be seen if this trend will continue into the MDV/HDV market. That time is not now however, and it would not be a sound financial decision to invest in electric MDV/HDV for the DON at this time. Chapter VI discusses the EV market in greater detail.

### 3. Case Study Hybrid-Electric

Tables 42–45 show the NPV comparison for buses, tractor-trailers, step vans and vans. We used the same discount rate and years of service as our CNG case study. Estimates of the amount of CO2 produced was calculated through the Argonne National Laboratory's GREET model. We calculated the CO2 produced using a WTW analysis that examines energy use and emissions from the primary energy source through the operation of a vehicle. The NPV values are expressed in red parenthesis to indicate a negative value. All NPV calculations will be negative due to the fact there are no positive cash flows. Therefore, the greater the number the worse the investment.

Table 42. Hybrid-Electric Bus NPV Comparison

| | | | | |
|---|---|---|---|---|
| **Discount Rate** | 7% | | | |
| | | | | |
| **Type of Vehicle** | | Bus (Diesel) | | Bus (Hybrid) |
| **Purchase Cost** | | $465,000.00 | | $768,637.40 |
| **Miles/yr (VMT)** | | 16,311 | | 16,311 |
| **Years of Service** | | 15 | | 15 |
| **Fuel Cost/yr** | | $6,079.55 | | $5,150.84 |
| **CO2 produced (kg/mi)** | | 2.95 | | 1.61 |
| | | | | |
| **NPV** | | ($499,141.57) | | ($799,633.23) |
| **Per Mile** | | $2.04 | | $3.27 |

Table 43. Hybrid-Electric Tractor-Trailer NPV Comparison

| | | | | |
|---|---|---|---|---|
| **Discount Rate** | 7% | | | |
| | | | | |
| **Type of Vehicle** | | Tractor Trailer (diesel | | Tractor Trailer (Hybrid) |
| **Purchase Cost** | | $112,695.00 | | $1,261,034.00 |
| **Miles/yr (VMT)** | | 20,601 | | 20,601 |
| **Years of Service** | | 15 | | 15 |
| **Fuel Cost/yr** | | $8,446.41 | | $7,541.44 |
| **CO2 produced (kg/mi)** | | 2.12 | | 1.17 |
| | | | | |
| **NPV** | | ($160,618.65) | | ($1,305,892.33) |
| **Per Mile** | | $0.52 | | $4.23 |

Table 44. Hybrid-Electric Step Van NPV Comparison

| | | | | |
|---|---|---|---|---|
| **Discount Rate** | 7% | | | |
| | | | | |
| **Type of Vehicle** | | Step Van (gasoline) | | Step Van (Hybrid) |
| **Purchase Cost** | | $14,748.00 | | $222,032.00 |
| **Miles/yr (VMT)** | | 7,533 | | 7,533 |
| **Years of Service** | | 15 | | 15 |
| **Fuel Cost/yr** | | $1,824.71 | | $1,629.15 |
| **CO2 produced (kg/mi)** | | 0.99 | | 0.54 |
| | | | | |
| **NPV** | | ($27,337.28) | | ($233,958.88) |
| **Per Mile** | | $0.24 | | $2.07 |

Table 45. Hybrid-Electric Van NPV Comparison

| | | | | |
|---|---|---|---|---|
| **Discount Rate** | 7% | | | |
| | | | | |
| **Type of Vehicle** | | Van (gasoline) | | Van (Hybrid) |
| **Purchase Cost** | | $70,935.00 | | $167,823.20 |
| **Miles/yr (VMT)** | | 7,884 | | 7,884 |
| **Years of Service** | | 15 | | 15 |
| **Fuel Cost/yr** | | $2,218.91 | | $1,774.69 |
| **CO2 produced (kg/mi)** | | 2.95 | | 1.62 |
| | | | | |
| **NPV** | | ($86,339.73) | | ($181,723.26) |
| **Per Mile** | | $0.60 | | $1.54 |

Although our analysis indicates that hybrid-electric MDV/HDV is a better investment than electric MDV/HDV, with respect to our sample, the NPV difference shows that hybrid-electric is not a good investment. For example, a diesel bus from our sample fleet has a NPV of ($499,147.57) compared to a hybrid bus with a NPV of ($799,633.23) and electric with a NPV of ($1,005,929.60). Table 46 shows a NPV comparison between petroleum, hybrid and electric.

Table 46. Petroleum, Hybrid-Electric & Electric NPV Comparison

| Type | Petroleum NPV | Hybrid NPV | Electric NPV |
|---|---|---|---|
| Bus | ($499,141.57) | ($799,633.23) | ($1,005,929.60) |
| Tractor Trailer | ($160,618.65) | ($1,305,892.33) | ($1,647,827.74) |
| Step Van | ($27,337.28) | ($233,958.88) | ($297,912.66) |
| Van | ($86,339.73) | ($181,723.26) | ($229,516.86) |

#### *a. Purchase Cost Breakeven Analysis*

Figure 62 shows a purchase cost breakeven analysis for buses in which NPV for hybrid-electric buses equals that of diesel buses. For example, Figure 62 shows that if a diesel powered bus cost $450,000.00 to purchase, its hybrid-electric equivalent would need to cost $453,140.00 to have the same NPV, and therefore to be financially competitive.

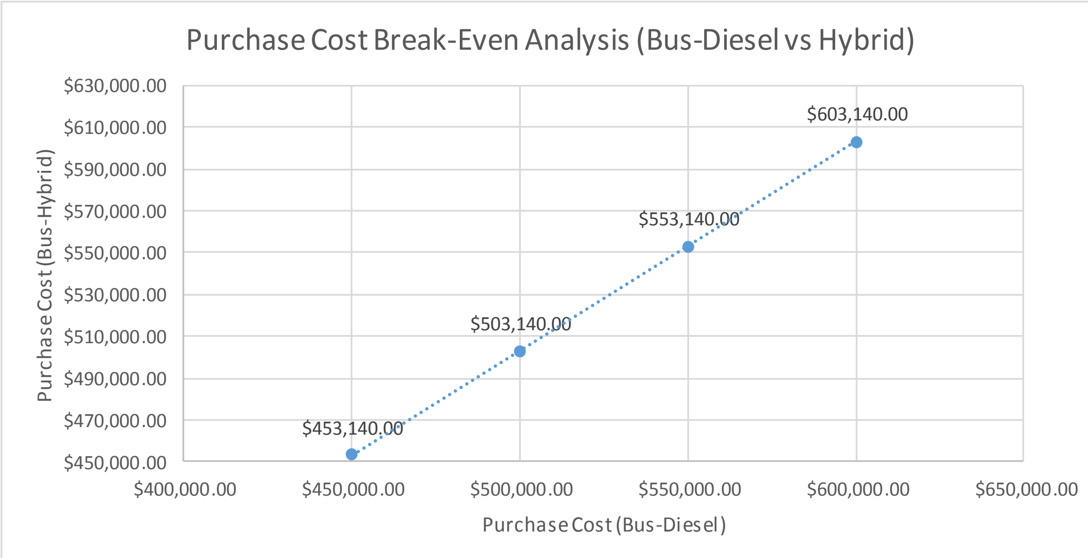



Figure 62. Hybrid-Electric Purchase Cost Breakeven Analysis

When comparing the data in Figure 62 to electric buses we found that the breakeven purchase cost for hybrid-electric buses would have to be lower than that of electric buses. For example, if a diesel bus were purchased for $500,000.00, then its hybrid-electric equivalent would need to cost $503,140.00 and electric equivalent would need to cost $521,400.00. The reason for this is that HEVs do not enjoy the same amount of savings with respect to fuel as EVs do.

We calculated with respect to our sample that electric MDV/HDV save on average 78 percent in fuel cost compared to 13 percent for hybrid-electric MDV/HDV. Additionally, electric MDV/HDV save on average 40 percent in maintenance cost compared to no saving with hybrid-electric. These two disparities in savings reduce the flexibility that fleet managers might have when weighing alternatives. For example, when we analyzed electric MDV/HDVs, we found an opportunity for electric to become more viable by increasing annual miles traveled per vehicle. The reason that better utilization enhanced electric MDV/HDVs is because fleet managers could take advantage of the significant savings in fuel and maintenance costs. Hybrid-electric MDV/HDVs does not provide the same level of savings therefore reduce the flexibility in which fleet managers can save.

The break-even analyses for all vehicles are located in Table 47.

Table 47. Hybrid-Electric Breakeven Purchase Price (All Vehicles)

| | Diesel Purchase Cost | | Hybrid-Electric Break Even |
|---|---|---|---|
| **Bus** | $450,000.00 | | $453,140.00 |
| | $500,000.00 | | $503,140.00 |
| | $550,000.00 | | $553,140.00 |
| | $600,000.00 | | $603,140.00 |
| | | | |
| **Tractor Trailer** | $100,000.00 | | $103,000.00 |
| | $150,000.00 | | $153,000.00 |
| | $200,000.00 | | $203,000.00 |
| | $250,000.00 | | $253,000.00 |
| | | | |
| **Step Van** | $15,000.00 | | $15,600.00 |
| | $25,000.00 | | $25,600.00 |
| | $35,000.00 | | $35,600.00 |
| | $45,000.00 | | $45,600.00 |
| | | | |
| **Van** | $60,000.00 | | $61,500.00 |
| | $70,000.00 | | $71,500.00 |
| | $80,000.00 | | $81,500.00 |
| | $90,000.00 | | $91,500.00 |

### *b. Conclusion*

Hybrid-electric MDV/HDVs are less harmful to the environment than petroleum MDV/HDVs, but they are worse investments. Furthermore, we calculated hybrid-electric saved, on average, 13 percent in fuel savings, which does not meet the Secretary of Navy's mandate for reducing petroleum by 50 percent. Additionally, the purchase price is still too high to justify the investment.

Hybrid-electric technology is a more mature and widely used technology than either CNG or electric within the LDV market. Our research shows that this trend has not continued into the MDV/HDV market. The biggest attribute that hybrid has is the fact that there is no additional infrastructure required to support a MDV/HDV fleet. That attribute however does not offset the minimal efficiency gain and high purchase cost.

# VI. CONCLUSIONS

Through our analysis, we found that investing in CNG, electric and hybrid-electric in not a sound financial decision at this time for MDVs and HDVs. To compare each powertrain, we used a Life Cycle Cost Estimate that compared each vehicle based on the following costs: purchase price, infrastructure, maintenance and fuel. For these comparisons, we took the cost for purchase, maintenance, electric infrastructure and fuel from our analysis in Chapter V. For CNG infrastructure, we allocated an amount of $50,000.00 per vehicle based on market data (Smith, M., & Gonzales, J., 2014).

## A. VEHICLE TYPES

The following sections provide the results of the analysis of the five vehicle types selected from Chapter III.

### 1. Buses

Figure 63 shows a bus lifetime cost comparison based on the type of powertrain installed. The total lifetime cost for each powertrain is as follows:

- Diesel - $616,193.25
- CNG - $695,727.14
- Electric - $1,049,592.90
- Hybrid - $905,900

CNG is the most competitive with regard to diesel when assuming an infrastructure cost. If infrastructure were already in place, the total lifetime cost would be reduced to $645,727.14. For electric and hybrid, the high purchase prices are the most significant drivers for their high lifetime costs.

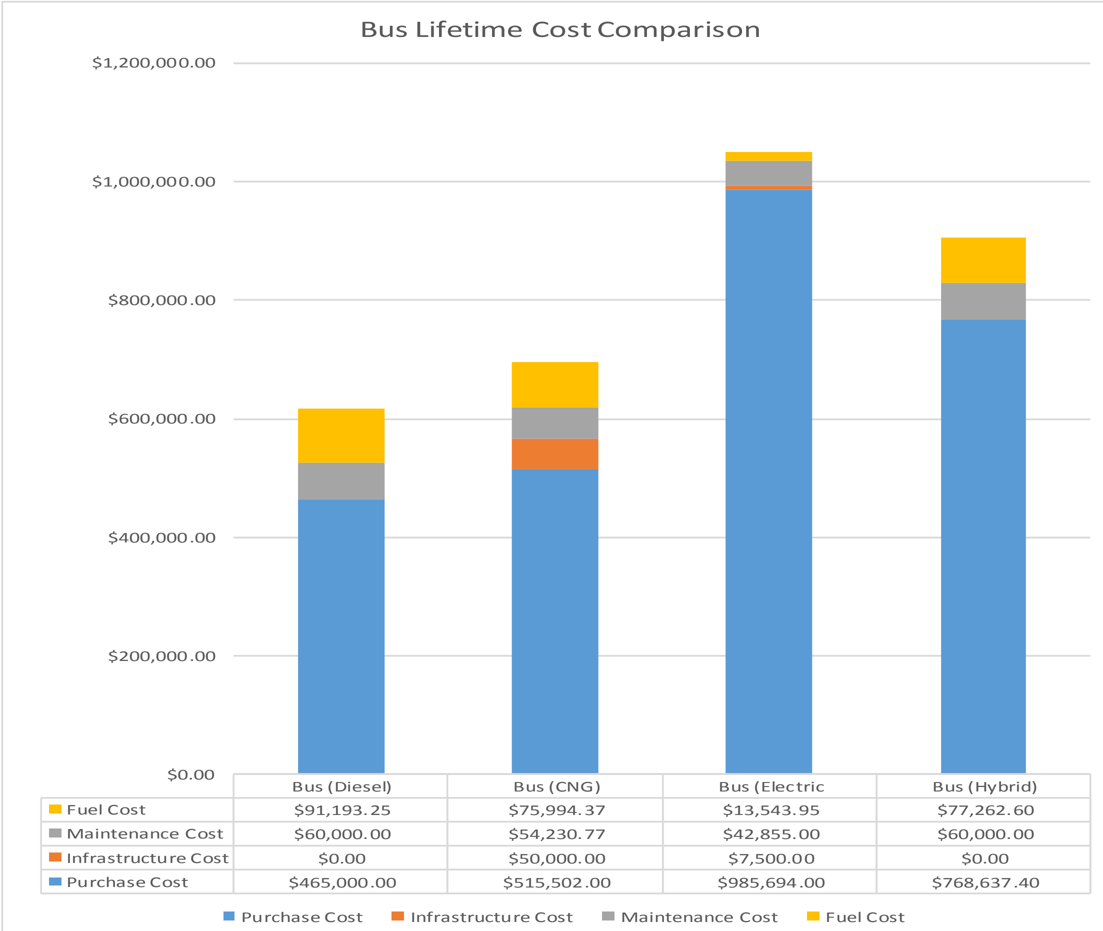



Figure 63. Bus Lifetime Cost Comparison

### 2. Tractor Trailers

Figure 64 shows tractor-trailer lifetime cost comparison based on the type of powertrain installed. The total lifetime cost for each powertrain is as follows:

- Diesel - $324,921.15
- CNG - $375,876.08
- Electric - $1,729,224.40
- Hybrid - $1,459,685.60

CNG is again the most competitive with regard to diesel. If infrastructure were already in place, the total lifetime cost would be reduced to $325,876.08. This was the most competitive comparison throughout our analysis and was due to the competitive purchase price and the fact that tractor-trailers were better utilized than all other vehicles in our study. For electric and hybrid, the high purchase prices are the most significant drivers for their high lifetime costs. The differences in purchase cost between hybrid, electric and diesel was most significant with tractor-trailers.

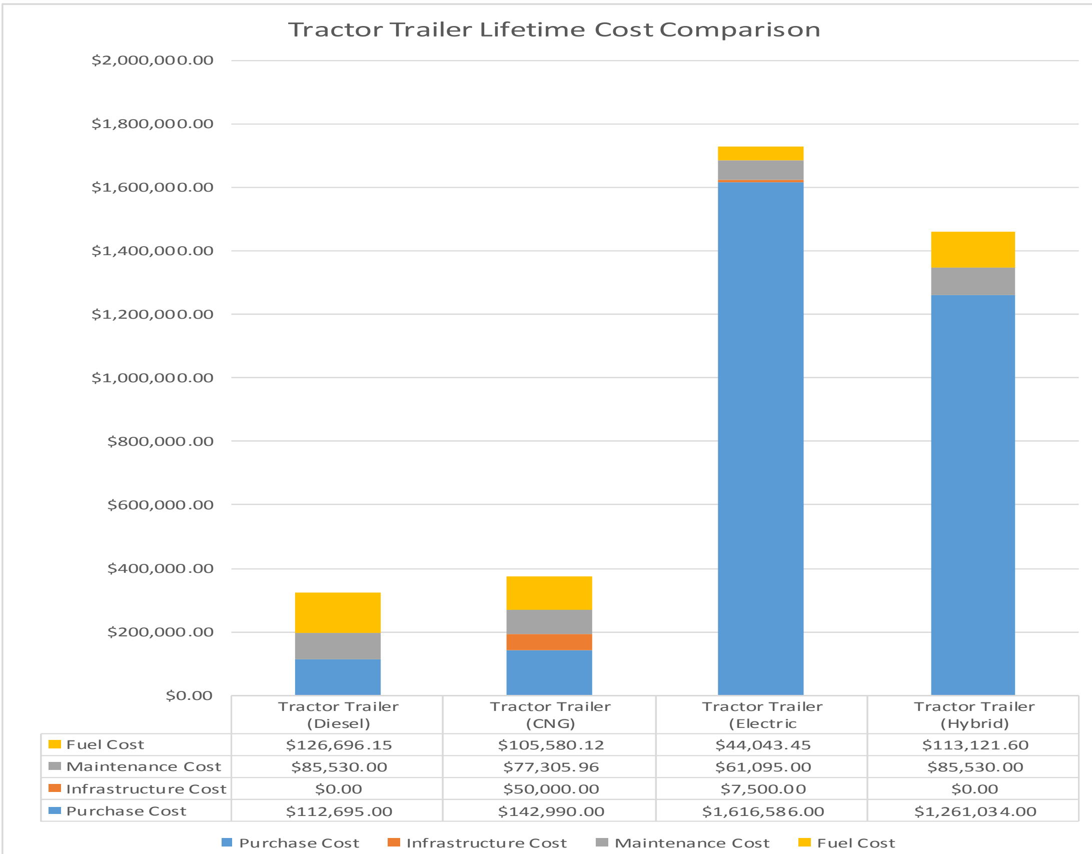



Figure 64. Tractor-trailer Lifetime Cost Comparison

### 3. Fire Trucks

Figure 65 shows fire truck's lifetime cost comparison based on the type of powertrain installed. The total lifetime cost for each powertrain is as follows:

- Diesel - $648,012.05
- CNG - $718,369.14

Our Fire Truck analysis was limited because electric and hybrid-electric technology was not available in this class of vehicle. CNG, however, was not as competitive as it was with tractor-trailers and buses. Subtracting the infrastructure costs reduces the total lifetime cost to $668,369.14. The difference between diesel and CNG after the infrastructure reduction is $20,357.09. As we saw with tractor-trailers, the difference between diesel and CNG after the infrastructure reduction was $954.93. The biggest reason for this is that fire trucks are the least utilized vehicle therefore cannot enjoy the same savings with respect to fuel costs.

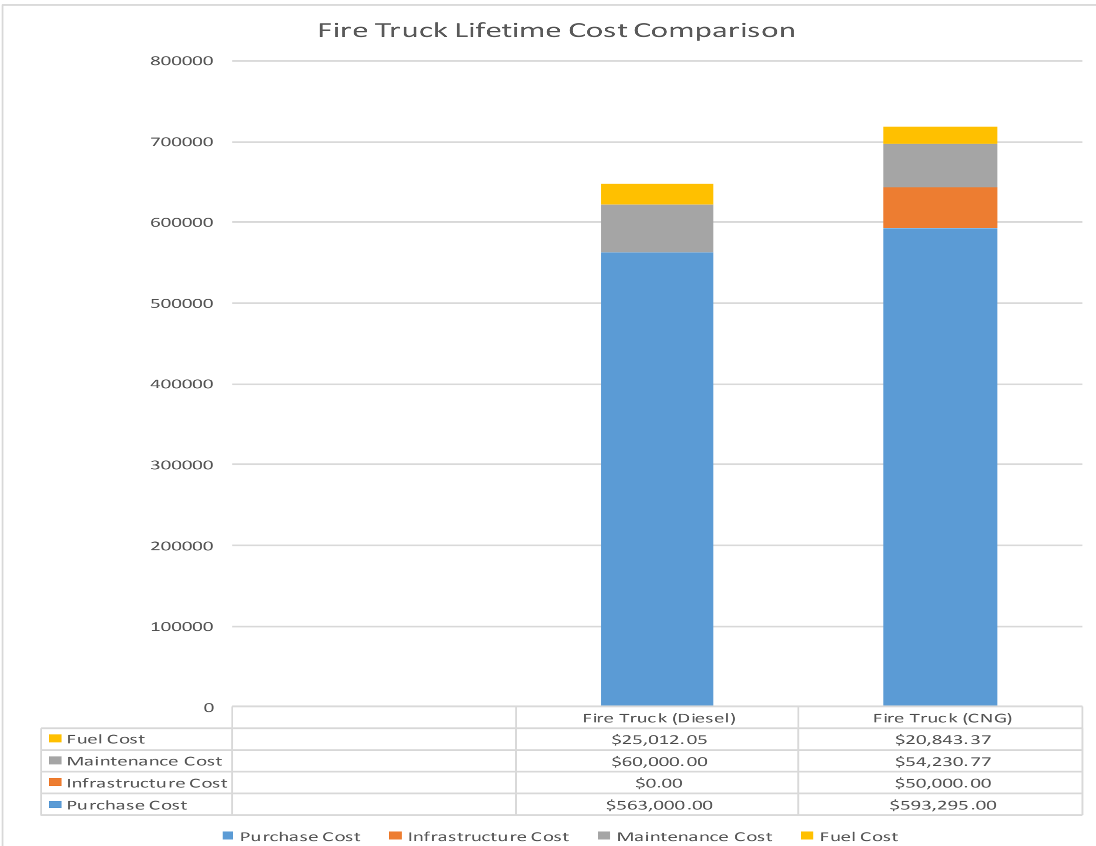



Figure 65. Fire Truck Lifetime Cost Comparison

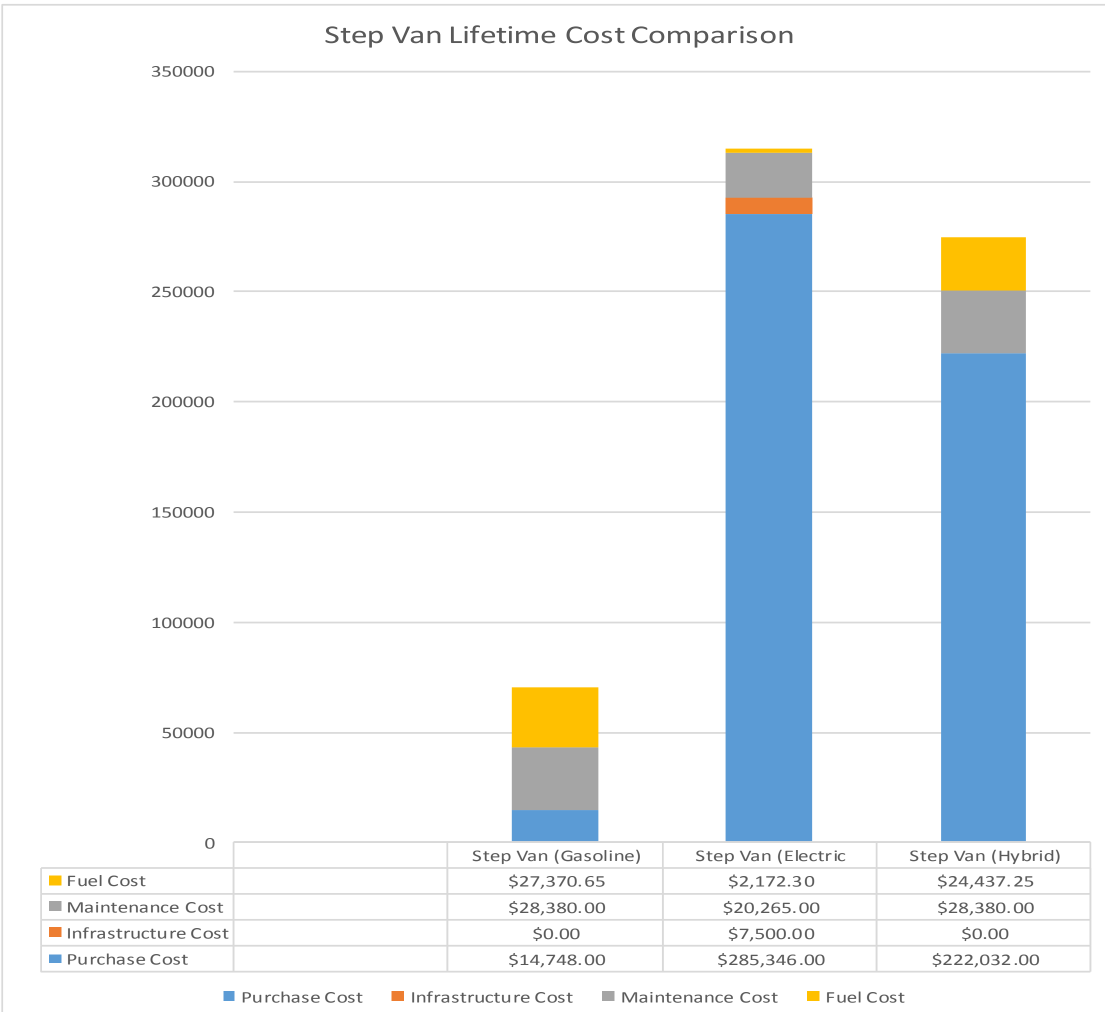
#### 4. Step Vans

Figure 66 shows step vans lifetime cost comparison based on the type of powertrain installed. The total lifetime cost for each powertrain is as follows:

- Gasoline - $70,498.65
- Electric - $315,283.30

- Hybrid -     $274,849.25

Our step van analysis was limited because CNG technology was not available in this class of vehicle. Although both electric and hybrid-electric saved in fuel, the high purchase cost could not justify a scenario in which either of these technologies were competitive with gasoline given current fuel rates.




| | Step Van (Gasoline) | Step Van (Electric | Step Van (Hybrid) |
|---|---|---|---|
| Fuel Cost | $27,370.65 | $2,172.30 | $24,437.25 |
| Maintenance Cost | $28,380.00 | $20,265.00 | $28,380.00 |
| Infrastructure Cost | $0.00 | $7,500.00 | $0.00 |
| Purchase Cost | $14,748.00 | $285,346.00 | $222,032.00 |

Figure 66.  Step Van Lifetime Cost Comparison

## 5. Vans

Figure 67 shows vans lifetime cost comparison based on the type of powertrain installed. The total lifetime cost for each powertrain is as follows:

- Gasoline - $139,153.65
- Electric - $250,466.05
- Hybrid - $229,378.55

Our van analysis was limited because CNG technology was not available in this class of vehicle. The van lifetime cost comparison was the most competitive in terms of total lifetime costs for electric and hybrid. As we seen with the LDV market in Chapter V, the smaller the vehicle with respect to electric and hybrid, the more cost comparable it becomes to the same size/type of petroleum vehicle. Vans were the smallest vehicle in terms of GVWR that we analyzed, which suggests it follows this trend.

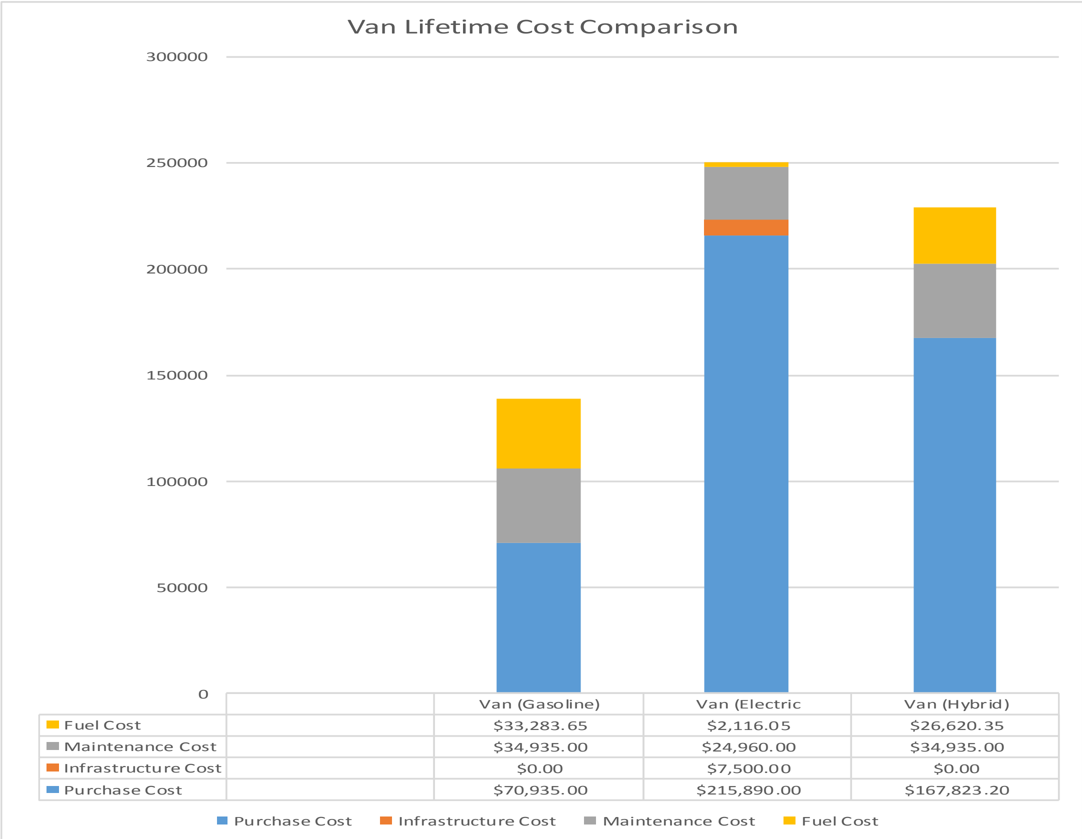



Figure 67. Van Lifetime Cost Comparison

## B. FINAL COMMENTS ON ANALYSIS

Although we found that investing in CNG, electric and hybrid-electric are not sound financial decisions at this time for MDVs and HDVs, some interesting trends were found.

CNG was a technology that was not prevalent in vans and step vans. Additionally, when evaluating the LDV market, we found CNG technology rarely utilized. CNG however, was the most cost competitive to diesel within our study. The three vehicle types in which CNG was applicable also happened to be in the HDV category. The most competitive that CNG got was within our tractor-trailer analysis, which also happens to be the biggest vehicle within our sample fleet. This suggests that CNG is best and most utilized in HDVs. Although we could not prove that CNG is a sound financial decision at this time, if diesel prices ($/gallon) were to increase to $3.05, CNG could become more desirable than diesel.

For electric and hybrid electric we found that, the smaller the vehicle the more cost competitive it would become when compared to petroleum vehicles of the same type/size. Unfortunately, the MDV/HDV market does not support electric and hybrid-electric at cost competitive rates at this time. The biggest reason for this is the high disparity in purchase costs. Perhaps, with improvements in battery technology, purchase costs for electric and hybrid-electric will decrease to a breakeven point. At this time however, those two technologies are not close to competing in the MDV/HDV market.

However, this analysis does provide transportation managers with a methodology by which they can compare AFVs as prices and variables change over time.

## C. MARKET CONSIDERATIONS

As mentioned previously, a business case could not be made for the DON to use electric, hybrid-electric, and CNG AFV technology at this time. The reasons are many, but primarily the market is still in its infancy and generally more favorable to LDVs, which results in a higher purchase price for MDVs and HDVs. That, coupled with low crude oil prices, have decreased the fuel savings that AFVs can offer the DON's medium- and heavy-duty fleet.

However, there are other market considerations the DON would be wise to consider. As indicated in Chapter V, medium- and heavy-duty vehicles have an average useful life of 15 years. Some vehicles, like certain models of the tractor-trailer, are kept for 20 years. Because of this, it is prudent to consider the direction in which the market is going so that the DON can analyze its strategy and position itself favorably as MDVs and HDVs are long-term investments. There are many variables to consider, but a few pertinent ones are examined below.

### 1. Crude Oil Prices

Chapter IV and V examine various alternative fuel commodities and weigh them against the historic price of gasoline or diesel. However, considering the long-term nature of MDV and HDV assets, a look at the projected future of crude oil prices is helpful.

As shown in Figure 29, the largest user of petroleum products, by far, is the transportation sector. Figure 68 shows projects that state while the fuel economy of new vehicles is expected to increase significantly, the worldwide vehicle fleet is expected to more than double by 2035. This signals that demand in the transportation sector will at a minimum remain stable, but more than likely increase (British Petroleum, 2016).

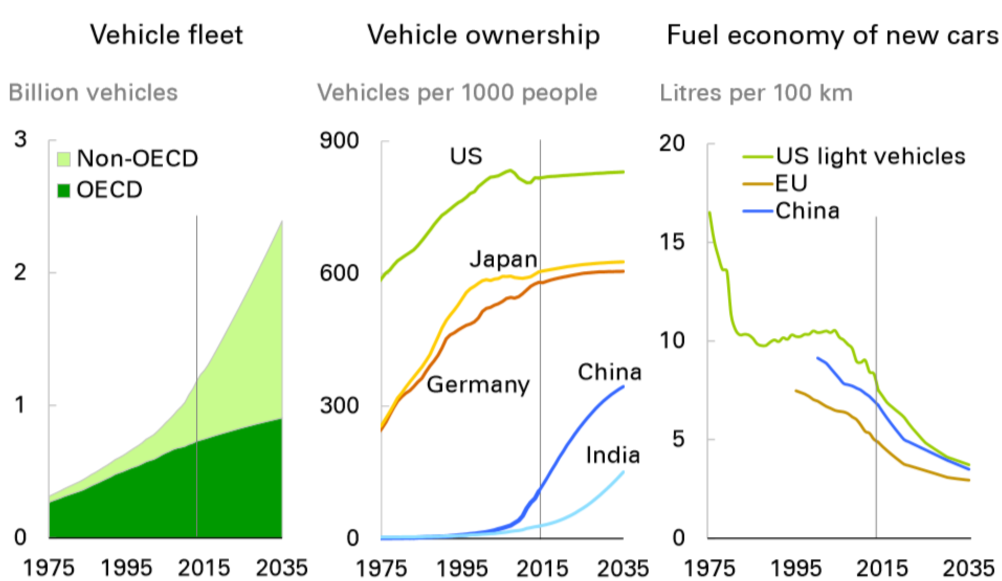



Figure 68. Global Vehicle Fleet Projections.
Source: British Petroleum (2016).

Additionally, Figure 69 estimates that vehicle miles traveled worldwide, will continue to increase through 2040. This reinforces the anticipated increased demand for the transportation sector over the next few decades.

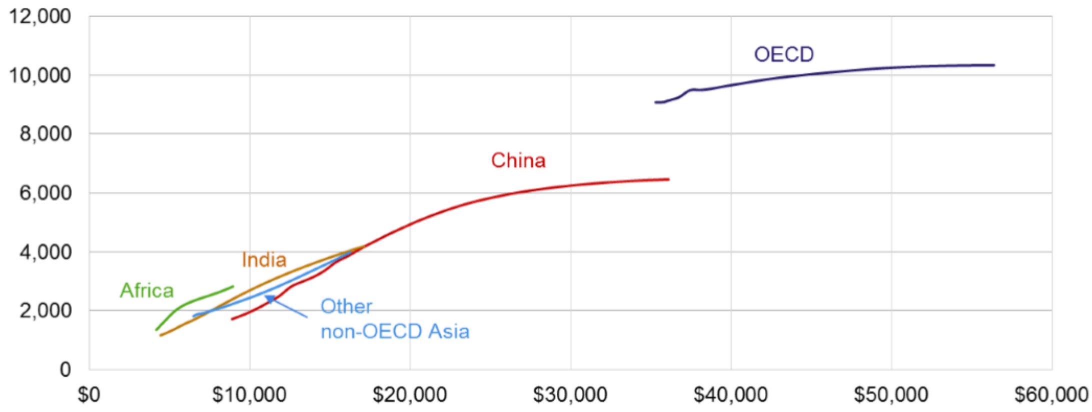



Figure 69. Passenger-miles Per Capita and GDP Per Capita for Selected Country Groupings 2010–2040.
Source: U.S. Energy Information Administration (2016b).

The question then becomes will petroleum demand within the transportation sector also remain the same or increase. If the projections in Figure 70 hold true, it shows that while diesel is losing the relative percentage of use over the next 25 years, overall diesel demand actually increases.

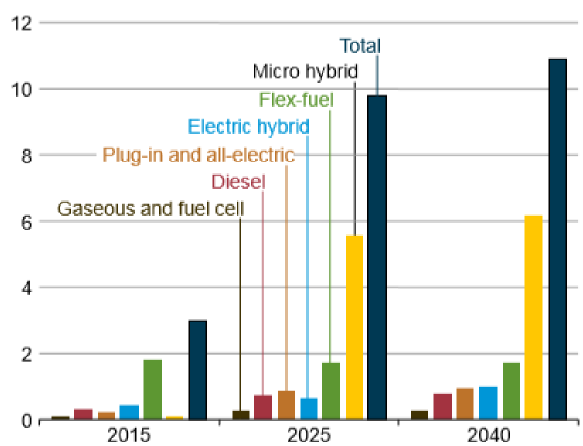



Figure 70. Vehicle Sales by Technology Type through 2040.
Source: U.S. Energy Information Administration (2016a).

Finally, Figure 71 shows crude oil price projections through 2040 with the reference case showing crude oil prices remaining relatively low over the next decade. From a strategic perspective, it is safe to say that the transportation sector will continue to grow worldwide, vehicle miles driven will increase, and while alternative fuels are projected to have more market share in the transportations sector, diesel and gasoline consumption will remain constant or increased. Couple this with an increase in supply over the same period in an already saturated market, as shown in Figure 72, and indicators point to gasoline and diesel prices that will continue to remain low over the next decade.

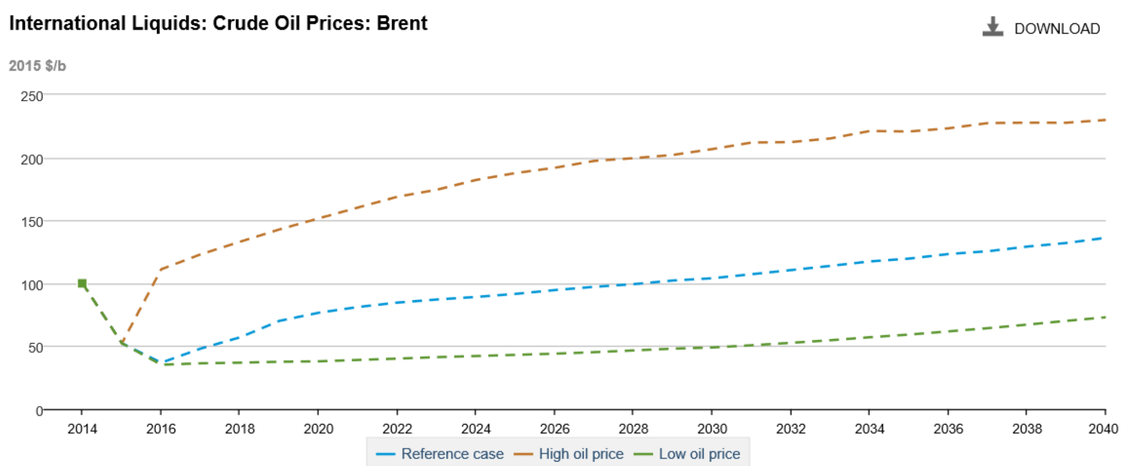



Figure 71. Crude Oil Prices to 2040. Source: U.S. Energy Information Administration (2016a).

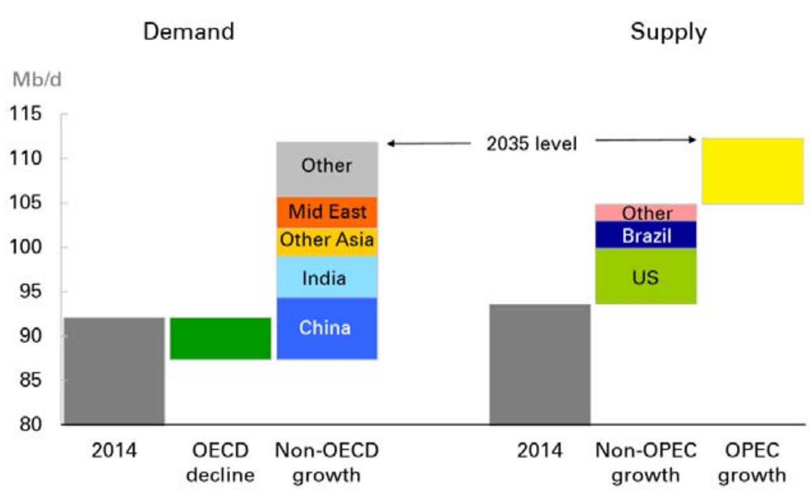



Figure 72. Oil Supply and Demand through 2035. Source: British Petroleum (2016).

## 2. Battery Technology

In 2010, the U.S. Energy Information Administration reported that the Electric Research Power Institute estimated lithium-ion battery storage to cost $950–$3,600 per kWh over the next decade. By 2013, the cost of storage ranged from $300–$1,000 per kWh over the same period, as shown in Figure 73. In 2016, Tesla's Model S offered an 80 kwh battery at a cost of $238 per kWh and the company has plans to hit $100 per kwh by 2020 (Straubel, 2015).

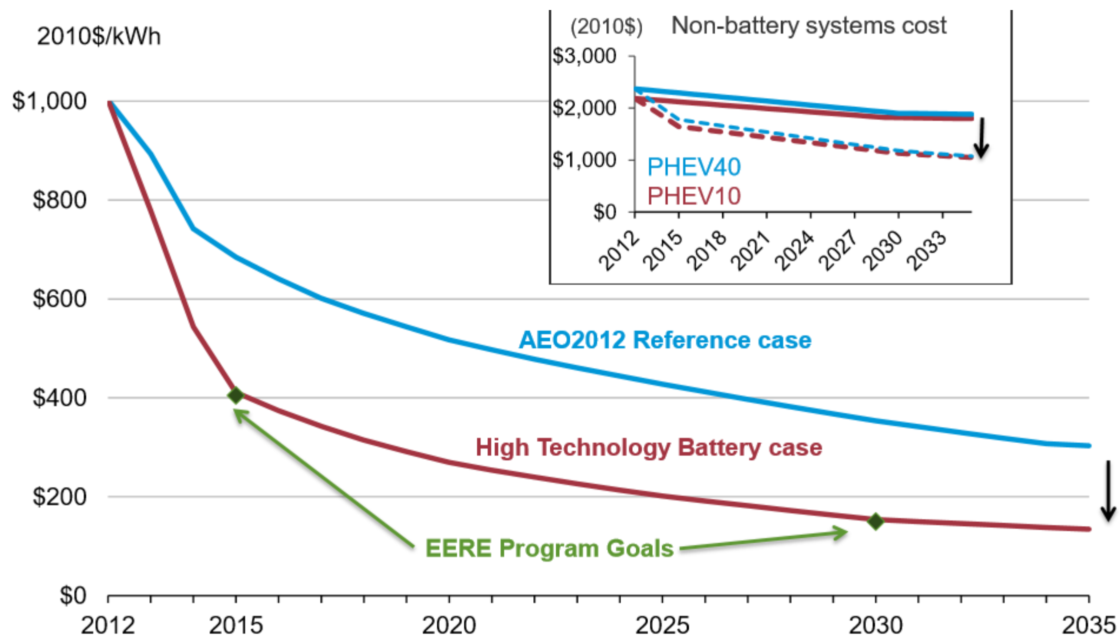



Figure 73. Lithium Ion Battery Cost Per kWh. Source: U.S. Energy Information Administration (2013).

Figure 74 shows that in addition to dramatically reducing costs, the lithium-ion battery industry has produced significant gains in energy density as well. In conclusion, battery storage technology continues to surpass energy density and cost per kWh projections. The electric and hybrid-electric markets are continuing to cut costs in the most expensive element of the vehicle, battery storage. Any long-term investment decisions should consider this when looking out over the next 15–20 years.

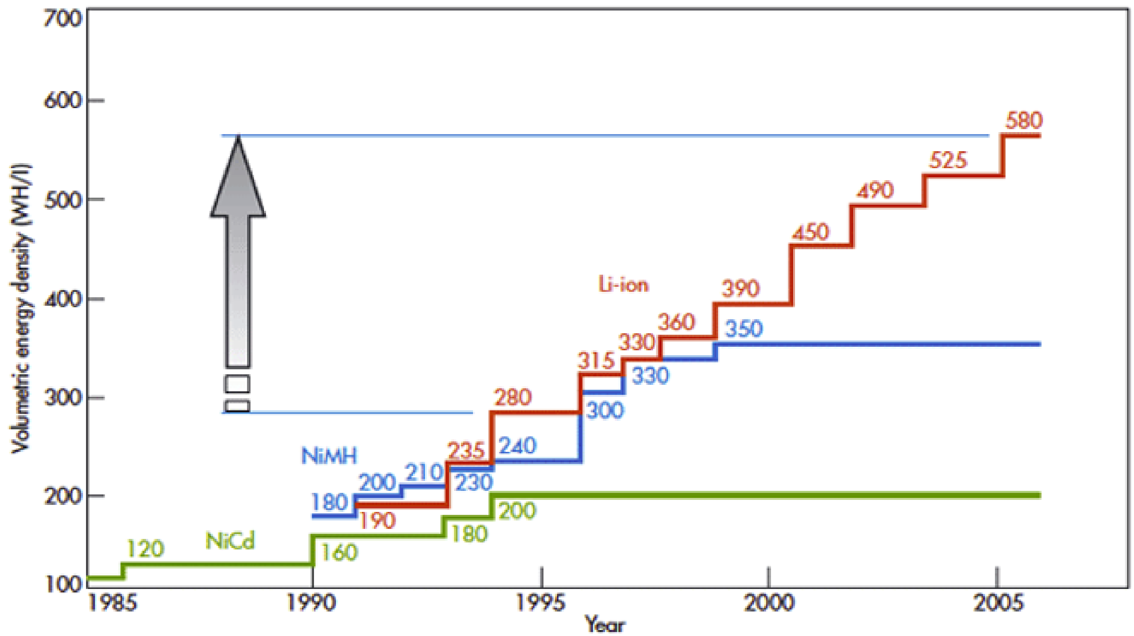



Figure 74. Battery Energy Density over Time. Source: Straubel (2015).

### 3. Increased Infrastructure Investments

Chapters II and IV addressed several reasons for increased investment in AFV technologies. Some are incentives and others regulation aimed at reducing the U.S. dependency on fossil fuels and decreasing GHG emissions. However, when looking at when considering which AFV technology to invest in, available infrastructure becomes a key issue and cost driver.

Figure 75 shows that electric charging infrastructure is receiving the heaviest investment and distribution in the U.S., surpassing all other AFV technologies combined from 2012–2015. This availability in infrastructure signals a robustness in electric and hybrid electric technologies, and Figures 76 and 77 reinforce this by showing the growing nature of the electric and hybrid electric market through vehicle sales.

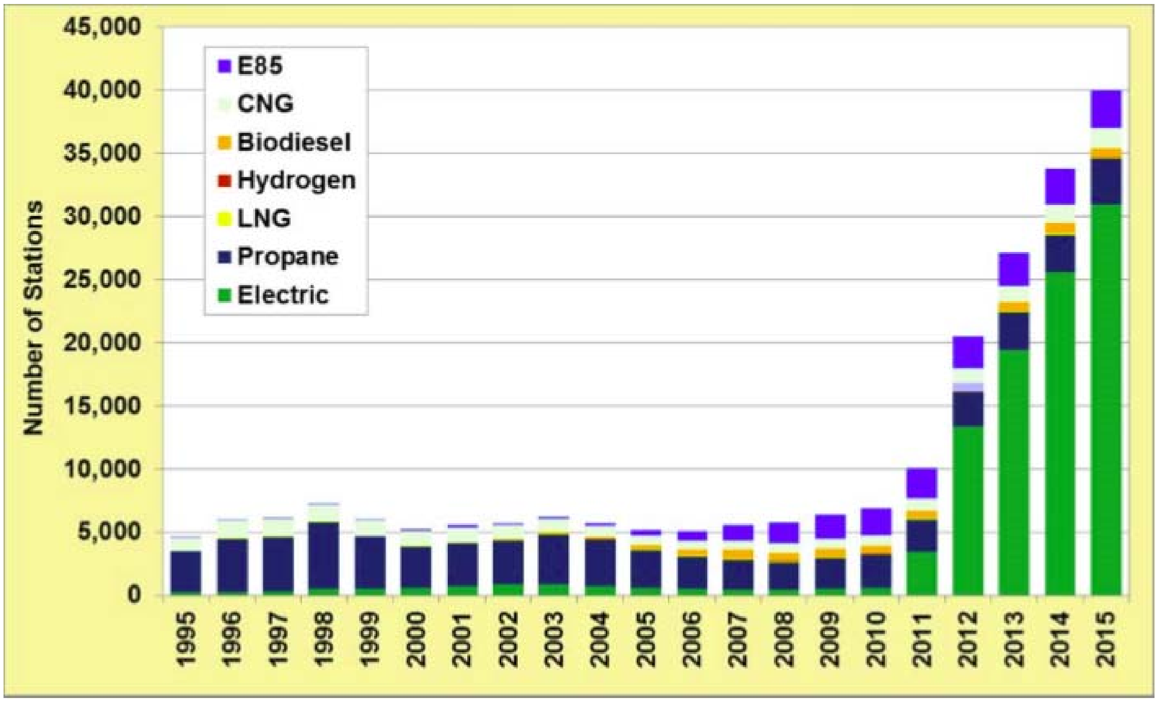



Figure 75. Alternative Fueling Stations by Fuel Type from 1995–2015.
Source: Oak Ridge National Laboratory (2015).

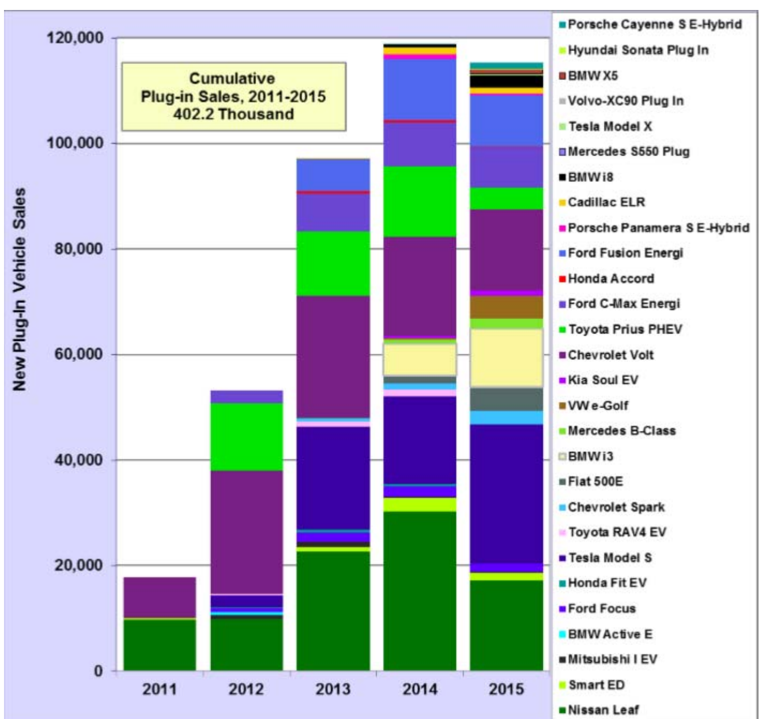



Figure 76. Plug-In Electric Vehicle Sales from 2011–2015.
Source: Oak Ridge National Laboratory (2015).

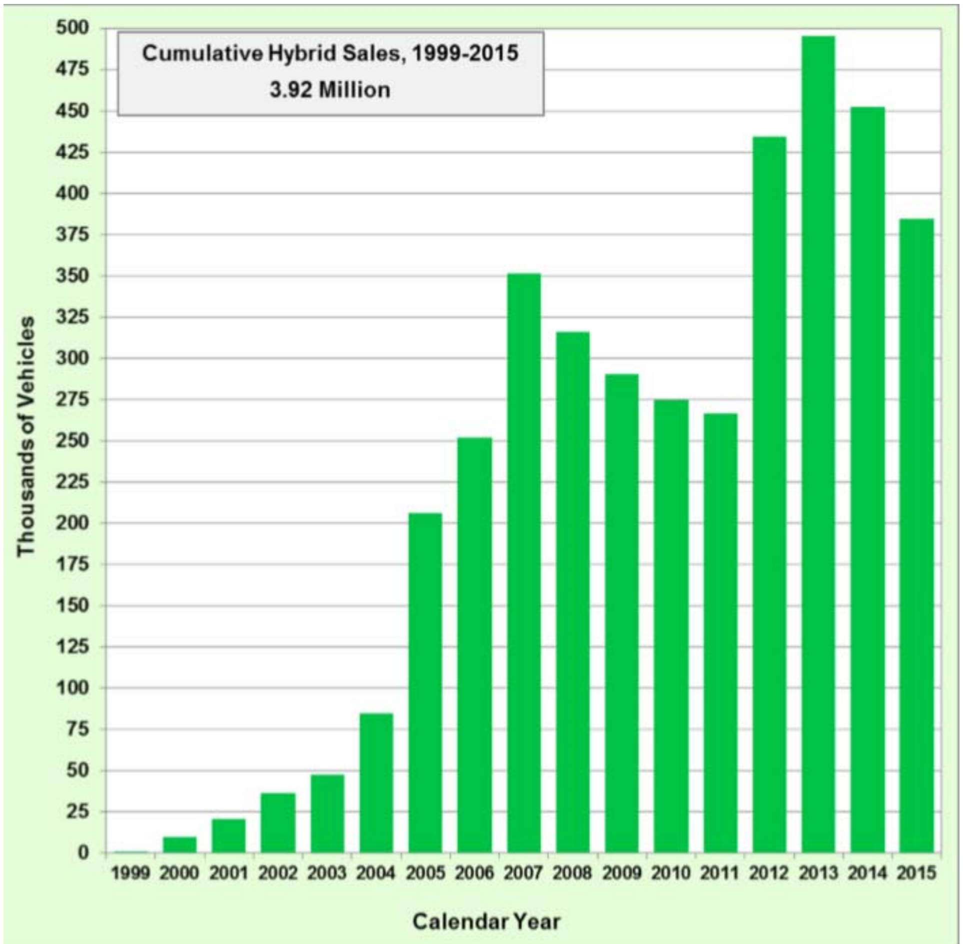



Figure 77. Hybrid Electric Vehicle Sale from 1999–2015. Source: Oak Ridge National Laboratory (2015).

### 4. Considerations for Fleet Managers

Ethanol remains the largest AFV technology utilized in the federal government vehicle fleet as shown in Figure 78 and continues to show signs of growth. However, electric vehicle acquisition of electric and hybrid electric AFV technologies are the second leading growth sector in federal government acquisition. As the DON strives to meet its goals, electric AFV technologies show the most potential. The significant gains in energy storage and energy density in battery technology, the explosion of infrastructure growth across the U.S. in the last few years, the maturity of the market, and the federal government's investment in this technology point to future cost reductions and potential for investment over the next decade. While Chapter V concludes that a business case does not at this point exist for MDVs and HDVs at this time, it may not remain the case over the next decade. Fleet managers should be cognizant of this and continue to watch how the electric vehicle market matures over the next few years.

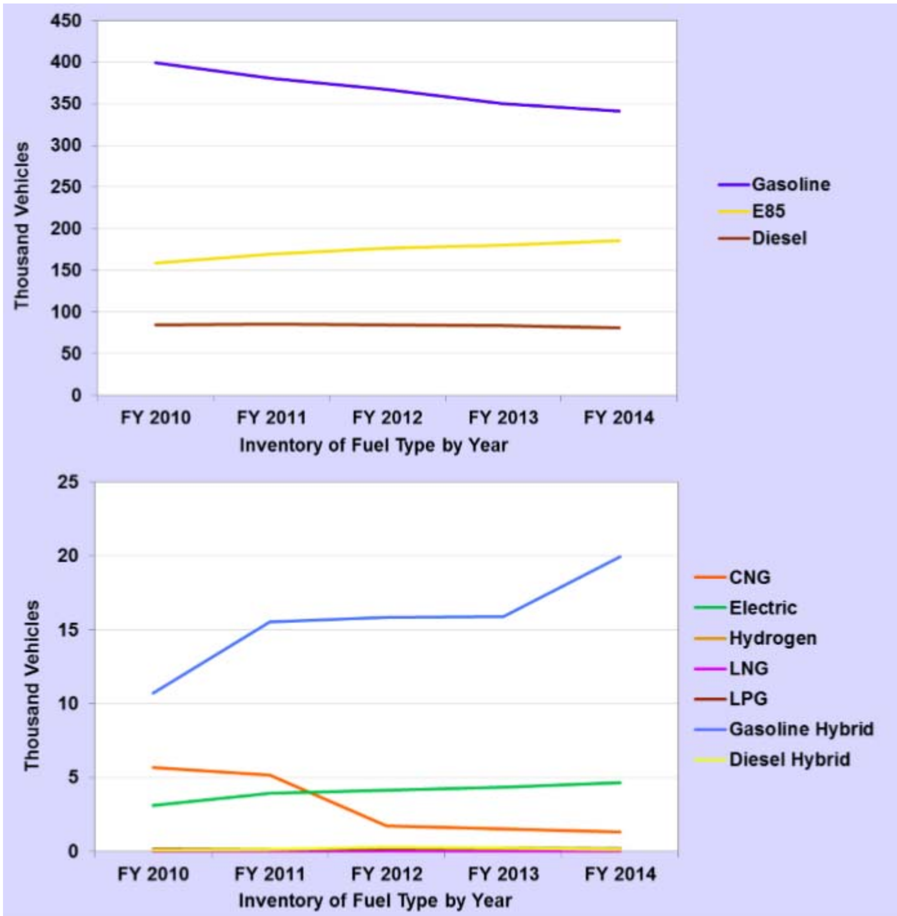



Figure 78. Federal Government Vehicles by Fuel Type.
Source: Oak Ridge National Laboratory (2015).

## D. AREAS FOR CONTINUED STUDY

This project looked at several AFV technologies and assessed whether a business case existed for the DON to replace their MDV and HDV assets within their NTV fleet. Through the course of research and analysis, many areas found that warranted continued study. This paper proposes the following areas of continued research.

### 1. Vehicle Conversions

For larger vehicles where purchasing an electric or hybrid electric drive does not make sense because of the large initial investment, vehicle conversions may provide a cost effective way to meet the DON's energy goals. Many companies offer to turn gasoline or diesel engines into hybrid-electric engines. Cost vary depending on the battery storage, but the addition of hybrid-electric technology will generate fuel savings through increased fuel economy. A study of current MDV and HDV vehicles and various costs for conversions may generate quicker payback periods and a case for limited investment.

There are even companies that offer to convert gasoline or diesel engines into CNG or Biodiesel vehicles. A study of the costs of doing so may provide a legitimate business case for investment.

### 2. Acquisition

There are many non-financial variables outside of the business case submitted in Chapter V that come into effect since any procurement must go through the DON's acquisition process. One of the issues to address is the requirement to buy American made products. Many of the AFV technologies are coming from non-American sources. If the DON determines that it is more important to meet energy goals, it should address the requirement to buy American and request a waiver.

Additionally, transportation assets currently are required to be purchased through the GSA listing unless GSA provides a waiver to agencies authorized to purchase transportation equipment. When conducting market research, it was found that many AFVs on the market are currently not on the GSA schedule, and therefore, many agencies are not taking advantage of potential AFV opportunities that exist in the marketplace. A thorough review of the listing schedule should be conducted to determine if AFVs currently not on the list could be added, or waivers procured by agencies wishing to use that specific AFV technology.

### 3. Incentives

Many federal and state incentives exist to meet GHG reductions and use alternative sources of energy. Currently, the DON is ineligible, as a federal agency, to take advantage of many tax incentive programs. However, through third party financing, the DON may be able to receive the benefits of these incentives through contracting with a firm that can use those tax credits. Additionally, bases may be able to take advantage of state incentives if they purchase their utility commodities from a state that has incentives for reducing crude oil or energy consumption. A study on incentives and how the DON may take advantage of them could help the DON make a business case for certain AFV technologies.

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